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Experimental Plan for VBE CA-1

Garfield R. Mellema

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Defence R&D Canada – Atlantic

Technical Memorandum

DRDC Atlantic TM 2003-158

September 2004

Canada

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Abstract

This document outlines the experimental plan for the first Canadian Virtual Battle Experiment, VBE CA-1. It is intended to provide some context for the experiment and act as a blueprint and guide for its implementation and execution.

VBEs are being used by the Maritime Systems Group Technical Panel 1 of The Technical Cooperation Panel (TTCP MAR TP-1) to investigate the influence of Network Enabled Capability in a modular synthetic maritime environment. VBE CA-1 is the first of a series of experiments investigating the effect of sharing low-level passive sonar data. It was designed to use multiple subjects in multiple sessions of a human-in-the-loop experiment to produce statistically relevant results.

Résumé

Le présent document donne un aperçu du plan d'expérimentation pour la première expérience de combat virtuel du Canada, VBE CA-1. Il fournit le contexte de l'expérience et constitue un plan et un guide pour sa mise en oeuvre et son exécution.

Les VBE sont utilisées par le Comité technique 1 du Groupe d'analyse des systèmes de marine du Programme de coopération technique (TP-1 MAR TTCP) pour étudier l'influence de la capacité réseau dans un environnement maritime synthétique modulaire. La VBE CA-1 est la première d'une série d'expériences sur les conséquences du partage de données de sonar passif à faible puissance. Elle à recours à des sujets multiples dans des sessions multiples à intervention humaine afin de produire des résultats pertinents sur le plan statistique.

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Executive summary

Introduction

This document outlines the experimental plan for the first Canadian Virtual Battle Experiment, VBE CA-1. It was intended to provide some context for the experiment as well as a blueprint and guide for its implementation and execution.

VBEs are being used by the Maritime Systems Group Technical Panel 1 of The Technical Cooperation Panel (TTCP MAR TP-1) to investigate the influence of Network Enabled Capability in a modular synthetic maritime environment. VBE CA-1 is the first of a series of experiments investigating the effect of sharing low-level passive sonar data. It was designed to use multiple subjects in multiple sessions of a human-in-the-loop experiment to produce statistically relevant results.

Results

This document provides a detailed plan for the implementation of VBE CA-1. It describes the objectives and requirements for the experiment and the infrastructure to be used in its implementation. Procedures for the execution of the experiment and the use of human subjects are described. Plans for the collection and analysis of the experimental data and the dissemination of the experimental results are also provided.

This document provides a template for the planning and implementation of follow-on experiments in this or similar programs.

Significance

The use of human subjects mandated a Human Research Ethics Committee (HREC) review of this experiment. This was the first HREC-reviewed experiment completed at DRDC Atlantic. This experiment was the first VBE run at DRDC Atlantic in conjunction with a current international series of TTCP MAR TP-1 experiments, and the first to make use of the new Virtual Combat Systems (VCS) Group laboratory.

Future plans

This experiment is the first in a series aimed at investigating how the value of shared coalition data changes as the exchanged data becomes increasingly refined. Subsequent experiments will build on the results of this experiment and investigate data sharing with differing sets of tools and/or information.

Mellema, G.R. and Wentzell, T.E. 2004. Experimental Plan for VBE CA-1. DRDC Atlantic TM 2003-158. Defence R&D Canada – Atlantic.

Sommaire

Introduction

Le présent document donne un aperçu du plan d'expérimentation pour la première expérience de combat virtuel du Canada, VBE CA-1. Il a pour but de fournir le contexte de l'expérience et constitue un plan et un guide pour sa mise en oeuvre et son exécution.

Les VBE sont utilisées par le Comité technique 1 du Groupe d'analyse des systèmes de marine du Programme de coopération technique (TP-1 MAR TTCP) pour étudier l'influence de la capacité réseau dans un environnement maritime synthétique modulaire. La VBE CA-1 est la première d'une série d'expériences sur les conséquences du partage de données de sonar passif à faible puissance. Elle a recours à des sujets multiples dans des sessions multiples à intervention humaine afin de produire des résultats pertinents sur le plan statistique.

Résultats

Le présent document offre un plan détaillé de la mise en oeuvre de la VBE CA-1. Il décrit les exigences et les objectifs relatifs à l'expérience ainsi que l'infrastructure entourant sa mise en oeuvre. Les procédures à suivre pour l'exécution de l'expérience et le recours à des sujets humains y sont décrites. Il comprend également les plans de cueillette et d'analyse de données d'expérimentation et de diffusion des résultats de l'expérience.

Le document fournit un modèle pour la planification et la mise en oeuvre d'expériences ultérieures du présent programme ou d'autres programmes similaires.

Portée

Le recours à des sujets humains a demandé une révision de l'expérience par le Comité d'éthique en matière d'étude sur des sujets humains (CEESH). Il s'agissait de la première expérience révisée par le CEESH à être complété à RDDC Atlantique, et de la première expérience VBE menée à RDDC Atlantique dans le cadre de la série d'expériences internationales en cours du TP-1 MAR TTCP, et la première expérience à utiliser le nouveau laboratoire du groupe des systèmes de combat virtuel (SCV).

Travaux futurs

L'expérience est la première d'une série qui vise à étudier de quelle façon la valeur des données de coalition change lorsque les données échangées deviennent de plus en plus précises. Les expériences qui suivront se feront à partir des résultats d'expériences et serviront à étudier le partage de données faisant appel à différents outils ou à différentes informations.

Mellema, G.R. and Wentzell, T.E. 2004. Experimental Plan for VBE CA-1. DRDC Atlantic TM 2003-158. Defence R&D Canada – Atlantic.

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1. Introduction

1.1 Coalition Data Exchange

Information exchange among coalition partners has the potential to provide significant advantages in the prosecution of underwater warfare [1]. The degree to which that potential is realized however may be dependent on the available bandwidth between the platforms and their ability to process the received data. As sensor data is refined from sound pressure to target location, course and speed, the data volume decreases and its information content increases. One cost is latency. Another is the lost opportunity to undertake lower-level multi-sensor processing, such as cross-correlation or triangulation.

Exchanging sensor-level sonar data entails its own set of costs and complexities. High bandwidth connections as well as powerful and sophisticated processing techniques are essential to the successful utilization of multiple streams of sensor-level data. In return one gains the capability to significantly reduce the time required to achieve target localization and identification. The payoff is not infinite however; at some level the costs of increased data sharing outweigh the additional benefits, due primarily to diminishing returns. In order to make a good decision as to the most appropriate level at which to share data between platforms, one needs a sense of how these costs and benefits trade off.

The minimum level at which it is beneficial to share data depends strongly on the speed and sophistication of the data processing available at the source and the input requirements of the processing routines at the recipient. Although the minimum input level of an automated processing system can be clearly specified, in the case of a human operator the minimum beneficial input level may be more difficult to identify, as it may be masked by issues related to operator loading and comprehension.

An investigation of the potential benefits of low-level inter-platform sonar data exchange requires the examination of a series of scenarios in which sonar data at differing levels of development are exchanged. The value of the exchanged data can be assessed in terms of the quality of development of the local operating picture [11]. The experiment described in this document is the first experiment in a series aimed at conducting such an investigation.

1.2 Passive Sonar Track Association

A single target vessel will typically produce acoustic emissions at multiple frequencies [14][19]. These signals may propagate along multiple paths to a receiver and may be intermittent in time due to such external influences as variations in source or receiver

location or the local environment. Each emission is eventually represented over time to the sonar operator as a signal track segment[1] from a potentially unique source.

Passive sonar association is the process of associating signal track segments across time, frequency or bearing into master tracks that are common to a single source vessel [9]. Although rudimentary tools exist to assist the operator in this task, it can be very labour intensive and relies heavily on the operator's training and experience. The use of an automated passive sonar association system or aid has the potential to reduce this workload. Improved situational awareness in the underwater environment and a reduction in the response time to threats may be expected by increasing the effectiveness of the human operator and the potential use of information not previously available [10][17].

The development of composite master tracks from multiple track segments is an inverse problem. From knowledge of the local environment and the source and receiver locations it can be fairly straightforward to calculate the resultant track segments, but extremely difficult to reliably determine whether apparent relationships between multiple track segments correspond to a common origin.

In order to provide some insight into potential processes for automated track segment association, it is necessary to understand the decision process by which a human operator decides whether or not to associate track segments that appear to have originated from the same source into master tracks. The experiment described in this document is the first in a series of experiments aimed at investigating that process.

1.3 TTCP VBEs

The Technical Cooperation Program (TTCP) Maritime Systems Group (MAR) Technical Panel 1 (TP-1) was stood up to study issues of relevance to Command and Control (C2) and Information Management (IM). A specific goal of the group is to study the effects of coalition data sharing on tactical picture development. To achieve this, a series of Virtual Battle Experiments (VBEs) are being be performed by participating nations, as well as by the MAR TP-1 group as a whole. Prior to the start of the experiment described here, Australia had completed two VBEs addressing high level command and control issues and was planning for a third [6][7]. These experiments demonstrated that VBEs are a valid method for addressing command and control issues. The MAR TP-1 group also collaboratively planned and executed two joint international VBEs, VBE-B and VBE-C, which took place in May 2003 and April 2004 respectively.

The infrastructure developed for TTCP VBEs provides a synthetic environment and combat system testbed in which the sonar track sharing issue can be studied. The implementation of this experiment also provided the opportunity for Canada to exercise the infrastructure on its own and to contribute to the international effort. This experiment was the first of a series of experiments aimed at fulfilling that role.

[1] A signal track segment is a single sequence of bearing and frequency values in time, typically plotted on a bearing-time or frequency-time display, representing the apparent track of an acoustic source.

1.4 VBE Personnel

This experiment is a joint effort of the Virtual Combat Systems (VCS) and the Underwater Warfare and Data Fusion (UDF) groups at Defence R&D Canada – Atlantic. The VCS group at Defence R&D Canada is involved in learning about the appropriate application of the synthetic environments to problems of interest to the naval community and, in particular, to the work programs of other scientists. In September 2002, the UDF group was approached for a question that might be answered by these means. It is hoped that in the future, the VCS group will become a known resource to the lab (and perhaps beyond), and that the group will be approached whenever experimentation is seen as a possible means of answering a question or testing a new idea.

The main personnel involved in VBE CA-1, their positions and their responsibilities are listed in Table 1.

Table 1. VBE CA-1 Personnel

NAME	POSITION	RESPONSIBILITY
Garfield Mellema	UDF group (defence scientist)	Lead experimental design, run director
Tania Wentzell	VCS group (defence scientist)	Experimental design, run director
Jason Murphy	VCS group (computer scientist)	Software development and implementation
Okan Topcu	VCS group (NATO exchange officer)	Verification and validation
Dave Hackett	VCS group (Contractor)	Software development
Mark Hazen	Leader of Virtual Combat Systems (VCS) group	
Bill Roger	Leader of Underwater Warfare Data Fusion (UDF) group	

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2. Experiment Objectives and Conceptual Model

2.1 Focus, Objectives and Conceptual Model

2.1.1 Experimental Considerations

Virtual Battle Experiment CA-1 uses simulated maritime scenarios to provide information on the influence of shared coalition data on the effectiveness of a human sonar operator. The successful completion of this experiment requires that the key aspects be identified and addressed prior to its execution [13][18].

In order for this experiment to be effective, the operator must be presented with one or more maritime scenarios that use passive sonar to address a plausible operational requirement. The scenarios also need to be realistic enough that the experimental issues are well represented, but any additional details or procedures beyond that would only add to the complexity and risk of the experiment.

In order for the experiment to address the issue of shared sonar data, the scenarios must have a plausible source of potentially useful nonorganic sonar data. The scenarios also need to allow for the insertion of the nonorganic data without other significant changes to the scenario in order to allow an unencumbered comparison of cases with and without the shared data.

The scenarios must include an operator tasked to undertake some action, the outcome of which is clearly dependent on the organic and nonorganic data and the operator's comprehension of both. There should also be some metrics with which to evaluate the differences in the outcomes of the two types of scenarios.

The scenario needs to provide the sonar operator with sonar track segments, a motive for associating them, a tool with which to associate them, and some method of querying the operator's rationale when they are associated or disassociated. The degree to which the track segments are associated and the accuracy of the associations are useful metrics by which to infer the level of operator comprehension.

The experiment should encourage the collection of freeform subject feedback in order to raise subjective issues about the experiment and possibly suggest additional ways in which the outcome of the experiment might be evaluated. The collection of user feedback also recognizes the capabilities of the operators, and their suggestions could include ways of improving future experiments.

2.1.2 Objectives

The objectives of this experiment are to address the following questions:

1. How does the presence of nonorganic track-level bearings-only sonar information influence sonar operator effectiveness as represented by manual operational picture development?

2. What is the rationale used by a sonar operator to decide when to associate or disassociate passive sonar tracks?

The first objective presents the experiment as a hypothesis test to decide whether or not the presence of nonorganic sonar data changes the outcome of the experimental scenario. The answer could be found by comparing appropriately chosen metrics describing the state of development of the operational picture with and without an additional display presenting nonorganic data. Further consideration of these and other metrics could yield a more complete answer as to the direction and degree of influence.

The sonar time-bearing plot was chosen to represent the operational picture in this experiment because it provides a sufficient representation of the operator's level of understanding of the situation. The development of bearings-only sonar tracks into estimates of absolute position would have added unnecessary complexity to the operator's tasks.

The second objective is a discovery exercise, aimed at investigating the decision making process used by a sonar operator in the course of assembling an operational picture. The track segment association process is not easily described, as it is influenced to varying degrees by many different factors. The goal here is to collect information about the specific process used in each of many different track associations. This information can then be structured and analyzed to better understand the decision making process.

2.1.3 Conceptual Model

This experiment is executed as multiple independent runs of a computer simulation, each using a different human subject, with the objective of providing statistically relevant results. The role of the subject in this experiment is that of a sonar operator onboard a frigate using a towed array sonar to monitor vessel traffic in a narrow strait. The operator's task is to develop as complete an operational picture as possible using only passive broadband sonar information from the ownship and allied positions.

Passive sonar data is often presented to an operator in bearing and/or frequency versus time format as a time-sequence of independent scans. The presence of a nearby vessel is typically indicated by repeated intensity peaks at bearings and frequencies corresponding to the propagation paths and characteristic emissions from that vessel. After identifying repetitive intensity peaks in the scans as track segments, the operator can then proceed to associate those track segments that are believed to have a common origin across time, frequency and bearing. These time-consuming tasks require some level of training and skill on the part of the operator but the manual performance of most of these tasks was not relevant to this experiment. In order to limit the

complexity of this experiment without significantly diminishing its relevance, the passive sonar data is presented to the operator already in track segment form.

The complexity of the passive sonar picture can be altered by changing the number of targets, the number of propagation paths between the target vessels and the receiver, or the number of tonals[2] produced by each target in a narrowband scenario. Comprehension of a picture complicated by the multipath propagation is likely to be beyond the ability of a novice, untrained subject. The use of narrowband scenario presenting the operator with frequency as well as bearing information would require that the operator be presented with a much more complex display than in the broadband case. The use of multiple targets, each responsible for no more than one displayed track segment at a time, was deemed to make the scenarios sufficiently challenging to the operator without adding undue complexity to the overall experiment. The sonar operator is therefore required only to associate the track segments across time, not bearing and no frequency information is presented. Characterization of the multiple targets as anything other than surface vessels was also deemed unnecessary.

In order to adequately evaluate the influence of sonar track sharing, the shared sonar track segments must contain data that is potentially valuable to the operator and be available in a familiar format. In order to provide nonorganic data necessary to this experiment, a geographically remote allied vessel using a similar sonar, also providing full coverage of the travelled portion of the strait but from a different perspective, was included in the scenario. A navigational chart display, which indicated the position of the ownship in the strait, also showed the position of the allied ship. No other vessel information is available from the navigational chart display. In those cases where the operator is provided with nonorganic data, a third display shows the same type of sonar track segments, but from the perspective of the allied ship. The difference in the two perspectives is the bearing to targets and the detection ranges.

In a typical operational scenario, a vessel towing a line array needs to change course periodically in order to resolve bearing ambiguities inherent to the use of a towed array sonar. In this experiment both the ownship and the allied ship make occasional course changes of appropriate magnitude at appropriate intervals, but the sonar operator has no ability to influence these manoeuvres. Although the ability to influence ownship manoeuvres could improve the operator's ability to discriminate targets, providing this ability would have undermined the controlled conditions and repeatability of the experiment. In addition the courses of the target vessels are significantly constrained by the limited navigable waters of the strait.

The development of metrics by which to evaluate the operational picture developed by the sonar operator requires that truth data be available for processing following the experiment. This data was identified as the correspondence between the target vessels and the primary track segments presented to the operator, and the track components of each track association and disassociation decision. The timings of each track segment initiation and each association or disassociation decision are also included.

---

[2] single-frequency tones

The operator decision rationale objective requires that the operator be queried following each association or disassociation decision as to the reason for that decision. The query needs to be immediate but brief and unobtrusive enough that the operator's concentration was not significantly disrupted.

3. Experimental Requirements

This experiment investigates the interaction between a sonar operator and a passive sonar bearing-time display presented in a synthetic maritime environment. The conceptual model in the previous chapter described the overall interaction of the key parts of the experiment: the simulation infrastructure, the scenarios and the subject operators. In this chapter, the core requirements of each of those parts will be specified explicitly.

3.1 Simulation Infrastructure Requirements

The simulation infrastructure is used to present the sonar operator with a realistic representation of maritime tactical data and to record the interaction of the operator with that environment. The infrastructure must also support the experimental scenarios. The requirements of the infrastructure, based on the conceptual model, are as follows.

1. Show, on a navigational chart display, the position and movement of at least 10 vessels following paths at predetermined courses and speeds. Be able to restrict the information shown to that of the ownship and allied ship. The positions of all of the vessels will be logged.

2. Show, on a passive sonar bearing-time display, from the perspective of a designated ownship, broadband signal tracks corresponding to the other nearby vessels.

3. Show, on a second passive sonar bearing-time display, from the perspective of a designated allied ship, broadband signal tracks corresponding to the other nearby vessels.

4. The broadband sonar tracks will be plotted as time versus bearing. The direct path bearings will be calculated according to straight-line paths. The signals received from each nearby source will be updated periodically and the corresponding tracks will terminate and reinitiate according to the following formula.

    a. A track will be initiated when the signal-to-noise ratio (SNR) of the calculated signal exceeds a specified threshold m times within n updates. The signal source level will be determined by the source vessel type and attenuation due to spreading along the propagation path between the source and receiver. The attenuation will be calculated as 15 log R, where R is the length of the straight-line path between the source and receiver. A combination of fixed and random amounts of background noise will also be added to the signal.

b. The track will be terminated when the SNR of the received signal falls below the detection threshold for a specified number of consecutive updates. The track segments will be assigned unique identifiers. The signal and noise levels will be logged.

5. The track displays will include tools to permit an operator to identify individual track segments and associate them into a fused master track. The operator will also be able to disassociate a master track back into its component tracks. The association or disassociation time and the track identifiers will be logged.

6. The operator will be queried following each association or disassociation decision as to the rationale behind that decision and the results of that query will be logged.

7. Since this experiment will investigate influence of a very rudimentary level of data sharing, it will not be possible for the operator to electronically associate tracks between the ownship and allied ship track displays. The operator must make any associations between the data on the two displays cognitively and apply these association to either or both displays.

8. The operator will be able to adjust the origin and scale of the navigation and track displays.

9. The simulation and the operator interface must run in real time.

10. The stimuli presented to the operator and the response of the console to operator input must be predictable and repeatable.

11. The passive sonar chart displays must be synchronized to each other and the navigational chart display at all times.

12. The navigational and chart displays must appear on physically separate windows so that they can be viewed simultaneously.

13. All log files must use a common clock.

14. The Run Director, who is responsible for the execution of the experimentation session, must be able to monitor the operation and performance of the simulation, particularly the simulation time and the simulation time rate.

15. The number of vessels and their positions, courses, speeds and source levels must be specifiable by the Run Director prior to an experimentation run. The background noise levels will also be specifiable.

16. The simulation infrastructure must support at least 2, but preferably 4, independent operators as well as the Run Director. The log files of each user must be distinct.

3.2 Scenario Requirements

A minimum of three maritime scenarios will be required for this experiment, one of which will be used for subject training and demonstrations. Since each subject will be participating in two experimentation sessions, one with shared coalition data and the other without shared data, it is important that different scenarios be presented in each session in order to reduce the influence of learning on the results of the second session. Additional scenarios may also be useful as spares, but their use should be sufficiently distributed that later analysis would be able to indicate whether the sequence in which the scenarios were presented was a relevant factor in the experimental results. In any case, the scenarios must be easily comprehended by, and present clear objectives to, operators with varying levels of expertise.

The scenarios used in this experiment must include an ownship and an allied ship manoeuvring cooperatively in a narrow strait. A sufficient number of other vessels must also be travelling in the strait. The positions and movements of the ownship and allied ship must be conducive to the monitoring of the other vessels in the strait, preferably providing redundant views of a similar subset of the vessel traffic. It is essential that the sonar tracks produced by the ownship and allied ship sonars are sufficiently intermittent in time that it would be somewhat difficult for the operator to identify and reassemble segments that are likely to have originated from the same vessel. Ideally, this level of difficulty of this task would vary from simple and obvious to challenging and ambiguous.

There should be a sufficient amount of traffic within sonar range of the allied vessels to provide a complex but not overwhelming sonar picture to the operator. The complexity of the sonar picture may be due in some part to the presence of vessels having similar bearing rates at differing ranges and speeds. The allied vessels should make periodic turns consistent with target motion analysis (TMA) by a towed array equipped vessel. The vessel traffic in the strait should be at least bi-directional, if not multidirectional, but their movement must be consistent with that expected in a realistic maritime scenario.

Since one of the objectives of this experiment is to investigate the process by which an operator makes association decisions, the problem of correctly associating the track segments need not be necessarily tractable. It is necessary though, to know the origins of the track segments in order to evaluate the effectiveness of the various decision-making processes.

3.3 Subject Requirements

The subjects to be used as operators in this experiment should have at least a rudimentary understanding of how sonar is used to track sea vessels. They should also be able to follow the progress of a vessel on the navigational chart display. Neither training nor experience in tactical sonar operations is necessary for this experiment, although it may be a prerequisite for later experiments in this program.

The ideal candidate for this experiment would be technically competent in-house personnel who are at least familiar with acoustics and/or have naval military training.

3.4 Experimentation Plan Milestones

Table 2 provides a time line for the different phases of this experiment.

Table 2. *VBE CA-1 time line*

TASK	DATE(S)
Orientation Meeting	November 2002
Capabilities Analysis	December 2002
Requirements Analysis	January 2003
Initial Infrastructure Plan	February 2003
Conceptual Model	March 2003
Draft Experimental Plan	April 2003
Submit Proposal to the Human Research Ethics Committee (HREC)	May 2003
Demonstrate Simulation Infrastructure	June 2003
HREC Approval	July 2003
Demonstrate Scenarios	July 2003
VBE CA-1 Test Run	August 2003
Call for Volunteers	August 2003
Final Software Modification	September 2003
Experimental Plan – Final	September 2003
VBE CA-1 with Operators	September 2003
Completed Analysis	October 2003
Scientific Report of the Results	December 2003
Completion of Documentation	July 2004

4. Simulation Infrastructure

The experimentation sessions will take place in a simulated operations room environment. The simulation will include two independent sonar operator's workstations, each represented by a pair of computer displays, one showing a navigational chart indicating the position of the operator's own ship and the other showing passive sonar tracks from the ownship. A third display, showing passive sonar tracks from an identically equipped but geographically remote allied vessel may also be available at one of the stations. A keyboard and mouse will be available for the operator to interact with either of the ownship displays. A second keyboard and mouse will be available for the operator to interact with the allied ship display. The station with only two displays is designated as the Solo Subject Station while the station with access to the allied sonar display is designated as the Coalition Subject Station.

The information provided on the subject station displays will be provided by maritime simulation software running at a third station, designated as the Run Director Station. From this station the Run Director will initiate, control and monitor the experimentation sessions. The simulation software, described in the following section, executes predetermined simulated maritime scenarios, the development of which is described in the following chapter. Each of the simulation interfaces seen by the subjects are independent, receiving data from the simulation, but not providing data to the simulation or each other. They are described in Section 4.2.

4.1 Simulation Tool Components

The maritime simulation was constructed using Virtual Maritime Systems Architecture[1] (VMSA) based federates, each federate providing a component or subsystem capability to the simulation, allowing the simulation to be tailored to the needs of the experiment [3]. VMSA is High Level Architecture (HLA) compliant [21].

The experiment software can be organized into two parts, the first part dealing with the simulation of relevant aspects of the movement and acoustics of the vessels, producing both vessel movement and sonar tracks, and the second part displaying those tracks for the subjects to observe and interact with. For best performance, all components of the first part reside on the Run Director Station while the subject stations include only instances of the components that are necessary for the subject user, as shown in Figure 1. This also permits the number and configuration of the subject stations to be independent of the rest of the simulation.

[1] VMSA was developed by the Australian Defence Science and Technology Organization (DSTO). The architecture and many simulation components, called federates, were made available to DRDC Atlantic through a Memorandum of Understanding between Canada and Australia, Subsidiary Arrangement 18.

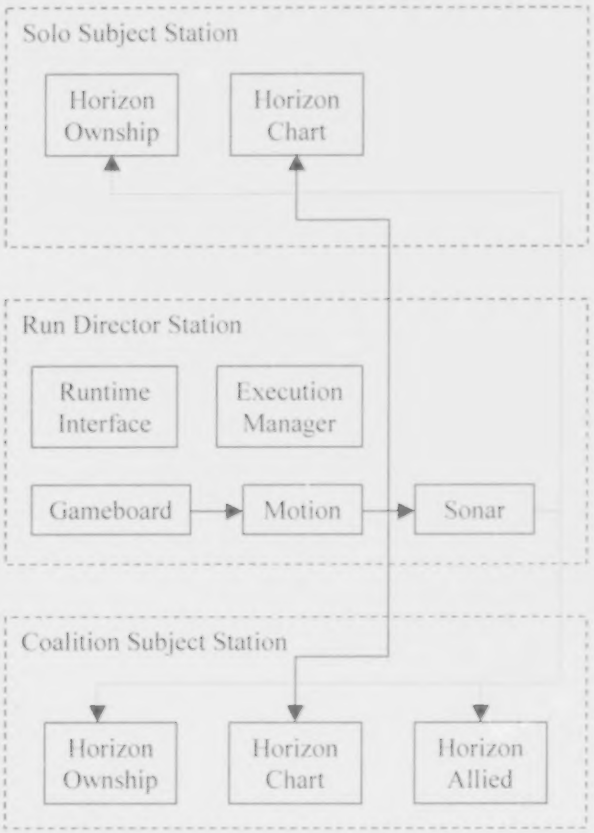

Figure 1. The simulation infrastructure can be separated into three parts.

The base component of the software running on the Run Director Station is the Run-Time Interface (RTI). The RTI provides an interface between each of the federates and the rest of the federation. The Virtual Maritime System Execution Manager (VMSEM) federate manages the pace at which the federation operates, ensuring that the simulation does not start until all of the federates have joined and that the federation time does not advance more rapidly than specified.

VMSA-based simulations are time managed, in that federates can be time constrained and time restricting, allowing them to be well controlled and repeatable. By taking advantage of this feature, the results of multiple independent runs of an experiment using different human operators can be analyzed to compile statistically relevant answers to address an experimental objective. Time regulation also permits Monte

Carlo analysis of the influence of changes in the experimental scenario, such as the replacement of processing algorithms or the addition of operator tools or shared coalition data.

In the VMSA, the course and speed of a vessel are controlled by commands from a helm federate that are translated into position, course and speed updates by a motion federate. In this experiment all of the helm commands are issued by an automated helm federate called Gameboard, which uses an XML script to manoeuvre vessels along predefined courses. The XML scripts are generated using a graphical scripting tool called Scenario Generator [16], as described in a later chapter. Although a federate exists to allow helm commands to be issued manually by an operator, this federate is not used since the scenarios used fixed the course and speed of each ship. Allowing the operators to manoeuvre the ships would jeopardize the repeatability of the experimental scenarios.

The original sonar federate available with VMSA is unsuitable for this experiment as it had been designed for use in scenarios that were more command and control oriented, and lacks most of those aspects of sonar signals that make them challenging to interpret and difficult to use. It was therefore necessary to construct a more suitable sonar federate following the requirements of Section 3.1.

The role of the sonar federate in this experiment is to observe the locations and types of each of the vessels and use that information to produce sonar track segments for display to the sonar operator. There is no requirement for the sonar simulation to follow the same processing steps as a real sonar or to precisely model every detail of the underwater environment so long as the end result has characteristics representative of real sonar tracks that would be experienced by an operator during a sea trial. A basic description of the requirements for the sonar federate in this experiment is as follows.

The sonar federate will:

1. calculate the signal excess of the received broadband acoustic emissions from each target vessel, taking into account:
   - the typical source level of that vessel type,
   - transmission loss calculated using a spherical-cylindrical model appropriate for medium range shallow water propagation,
   - interfering sources such as other nearby vessels, and
   - ambient noise, including randomly distributed fluctuations in the ambient noise.
2. When the signal excess exceeds a specified threshold at least m times within n simulation time steps, a sonar track segment will be initiated at a bearing corresponding to a direct path arrival from that vessel.

3. Once initiated, the track will be regularly updated so long as the signal excess does not fall below the specified threshold for more than a specified number of consecutive time steps.

4. Although there is no limit to the number of temporally distinct sonar track segments produced by each target vessel, each target vessel may produce no more than one track segment at any time and all track information will be discarded between segments.

5. For analysis purposes, the sonar federate will produce a log file detailing the initiation and termination times and conditions of each track, the track update values and the identities of the vessel or vessels to which each track corresponds.

The subject stations use multiple instances of Horizon, a track data hosting and management system provided by DSTO as an operator interface into the simulation [2]. Each instance of Horizon interfaces directly with the rest of the federation and each has a separate display. No information is passed between the Horizon instances or from Horizon into the rest of the federation although each instance of Horizon produces its own text and binary log files. Both the solo and coalition configurations of the operator station have a navigational chart display and a sonar display showing passive sonar tracks received by the ownship. The coalition configuration includes an additional display showing passive sonar tracks received by an allied ship.

The operator can associate and disassociate sonar tracks in Horizon, but Horizon does not query the operator as to the rationale for that decision, it merely acts on it. An overlay application, called EnterReason, was therefore constructed in-house to detect when the operator has clicked in the screen location of the associate/disassociate button and present a multiple-choice query as to the rationale for that decision.

The Run Director Station is hosted on a single computer, as is the Solo Subject Station. The Coalition Subject Station is hosted on a pair of computers, primarily due to the requirement for three instances of Horizon and three displays. Each computer is a dual processor 2.0 GHz Xeon with 1 GB of RAM running Windows 2000 and the stations are networked through a private 100 Mb/s switch to prevent interference from outside network traffic. This ensures that the experience of the operators will be predictable and repeatable. The federation rate, which is defined as the number of simulation time steps executed by the federation per second, is measured by the execution manger and shown on the Run Director display along with the simulation time step count. Real-time performance is considered to be one time step per second.

4.2 Simulation User Interface

This experiment compares the effectiveness of sonar operators having access to ownship data only with those having access to additional data from an allied ship. The experimentation sessions are therefore configured so that the only difference between the two types of operator stations is the presence of an additional sonar track display

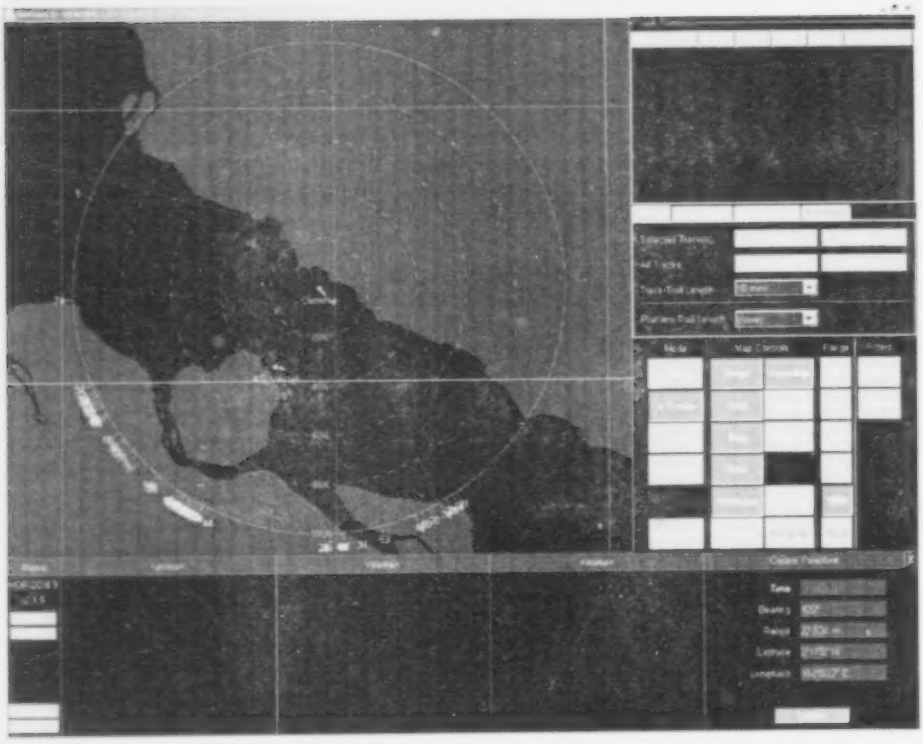

Figure 2. The Horizon chart display shows the local navigable waters and the locations of the ownship and the allied ship.

and its corresponding keyboard and mouse in the coalition configuration relative to the solo configuration.

Each subject station has a navigational chart display showing the local navigable waters and the positions of the ownship and allied ship as shown in Figure 2. The operator can adjust the scale and origin of the navigational chart display. Although additional vessel traffic is present in the local area, it is not shown on the navigational chart display. The only source of information regarding the additional vessel traffic is the intermittent sonar track segments on the passive sonar display, motivating the track association process.

Each subject station has an ownship sonar display showing sonar track segments that originated from the ownship towed array receiver. An example of a sonar chart display is shown in Figure 3. The ownship heading is shown as a series of filled grey circles while each sonar track segment is shown as a series of open yellow circles. A

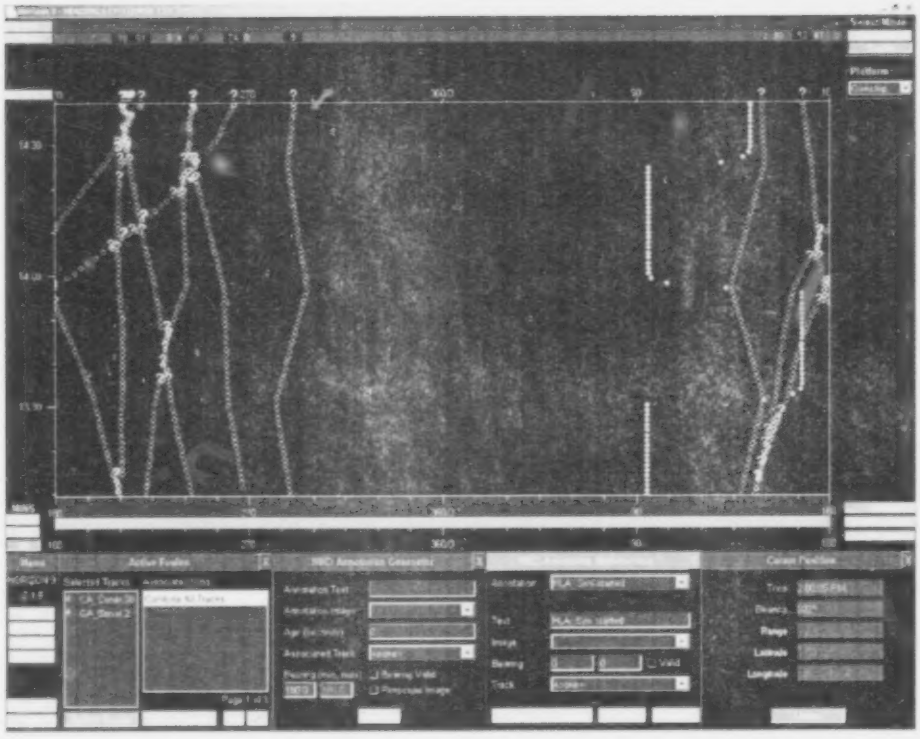

Figure 3. The Honzon time-bearing display shows sonar track segments such as these produced by the ownship sonar

question mark indicates the end of each track segment. The tracks are displayed in bearing versus time format and the time scale of the display is user-adjustable to show 30, 60 or 90 minutes of data. The user can also zoom in on a particular bearing range by dragging across it with the mouse.

Individual sonar track segments can be selected and deselected by clicking on them with the mouse and then associated into a fused track using the Active Fusion tool shown in the lower left of the display. Fused track segments are removed from the display and replaced with the fused track, drawn as a series of lightning bolt symbols. The Active Fusion tool can also be used to add additional track segments into a fused track or to disassociate a fused track back into its component track segments.

Although the operator at the Coalition Subject Station can see both the ownship and allied ship sonar displays and use information from one display to make decisions

Figure 4: The EnterReason popup appears whenever an association or disassociation is made.

regarding the other, information cannot be electronically associated between the displays.

Both the association and disassociation processes require that the operator click a button in a unique region of the display. Mouse clicks in this region trigger a query tool called EnterReason, which queries the operator as to the rationale that led to the association or disassociation decision. Several options are presented in a multiple-choice format, as shown in Figure 4, with a final choice of 'other.' Selecting the 'other' option opens a text box in which to elaborate. The options are read from a configuration file and the operator responses and decision times are logged to a file. The decision times are used to specifically identify the tracks being associated or disassociated, as the Horizon and EnterReason programs are not directly interfaced.

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5. Experiment Scenarios

The simulation infrastructure described in the previous chapter provides a platform in which to execute maritime scenarios. It is the position and movement of vessels in these scenarios that produces the simulated maritime environment necessary for this experiment. Five scenarios are available, one for training and demonstration purposes, two for use in experimentation sessions, and two others are kept in reserve as spares in case of unforeseen problems with the training or experimentation scenarios. Each of the maritime scenarios fulfills the requirements specified in Section 3.2.

The primary tool for scenario development is Scenario Generator, which produces an XML script file that can be read by the Gameboard federate to control the movements of the ownship, the allied ship and the other vessel traffic. Figure 5 shows the training scenario, T1, in Scenario Generator. Initial analysis of the scenarios is done using a tool called BearingGenerator, which reads the XML script files and translates the vessel positions over time into bearings relative to any other vessel over time. Figure 6 shows the same scenario in BearingGenerator. The bearing tracks produced by BearingGenerator are continuous in time, regardless of the received signal level or the presence of interfering sources.

A key requirement of the scenarios is the development of temporally distinct sonar track segments. The likelihood of a track being temporally disrupted is dependent on several factors including the target vessel source level, the nearby presence and strength of other sources, the ambient noise level, and the degrees of randomness in the background noise. All of these factors except the location of nearby sources can be modified in the configuration file of the sonar federate. The source level of a particular vessel can be modified in Scenario Generator by specifying the class of that vessel, e.g. freighter or frigate, or in the sonar configuration file by specifying the source characteristics of that class.

The experimental scenarios are intended to be difficult enough to be interesting, but not so difficult as to overwhelm novice operators. In the development of a typical scenario, the first few vessels produce sonar tracks that are relatively distinct and can be readily identified by a novice operator. As additional vessels are added, some of the classic complications can be seen, such as crossing sonar tracks, near-coincident sonar tracks due to multiple vessels at similar bearings with similar bearing rates, and the potential for track seduction, where a sonar track segment from one vessel is terminated while a sonar track segment from another is initiated.

The scenarios are developed by entering the configuration and routing of each vessel in Scenario Generator, generating an XML script file and then observing the resultant bearing tracks in BearingGenerator. In order to see how the scenario plays out with segmented sonar tracks, it is necessary to enter the script into Gameboard, run the simulation infrastructure and observe the results in Horizon. Each scenario is about 2 hours long and, due to limitations of the VMSA, the simulation can only be run from the beginning forward. Although the track generation federates can be run at higher

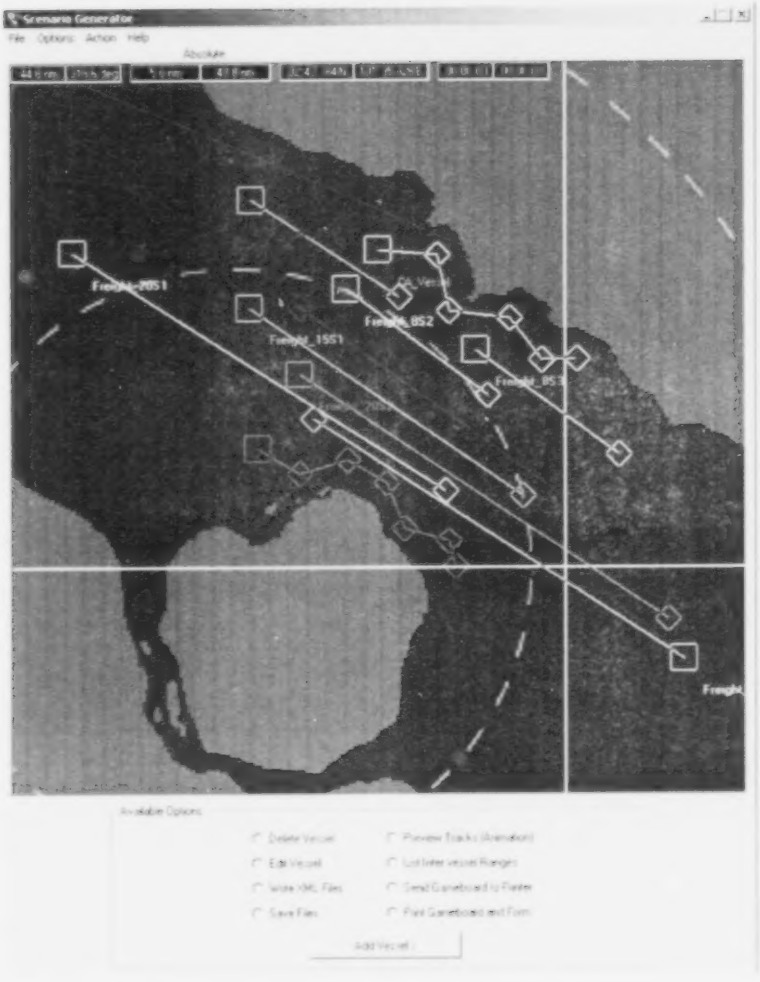

Figure 5: The scenarios used in this experiment were laid out using Scenario Generator. The training scenario, T1, is shown here.

speed, Horizon cannot, so the simulation is typically run without continuous observation while the scenarios are in development. Camtasia, a third-party display recording program from TechSmith, was be used to record the displays and then replay arbitrary portions of the scenario at variable speed. Following each simulation run, the scenarios are adjusted, either by changing the vessel characteristics or the sonar configuration until the scenario is deemed to be satisfactory.

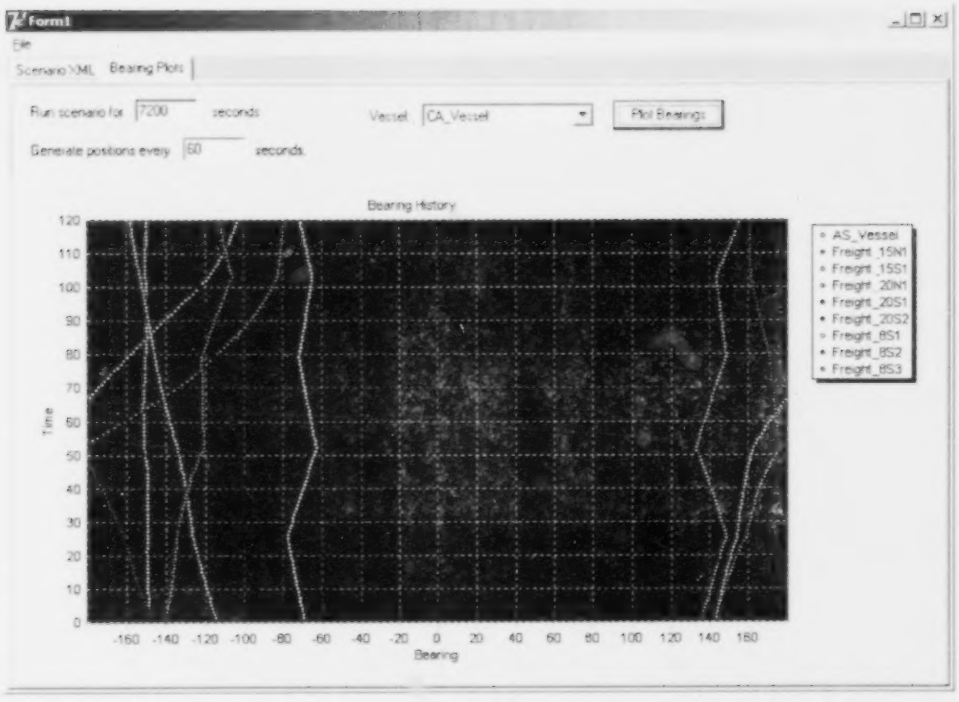

Figure 6. Initial analysis of the scenarios is done using BearingGenerator, which reads the XML script files and translates the vessel positions over time into bearings relative to any other vessel over time.

The iterative nature of scenario development is largely due to the use of random values in the sonar federate and the lack of tools to invert sonar tracks back into vessel tracks. However, the techniques used are sufficient for the purposes of this experiment. Since one of the objectives of this experiment is to investigate the process by which an operator makes association decisions, there is no requirement for a single, unique solution to the association problem. Each of the scenarios uses about 10 vessels including the ownship and the allied ship, and each of the two sonars produces approximately 150 distinct track segments during the 2 hour run.

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6. Operator Subjects

Although much of the work preparing for this experiment centred on the development of a maritime simulation, the heart of the experiment is not the simulation. The simulation is a component of the experiment. It is the interaction of the human subject with the simulation that is of primary interest. The human subject plays an essential role in this experiment. The purpose of this experiment is to investigate how additional, nonorganic data affects an operator's abilities, and learning about the decision-making processes employed by a human operator.

6.1 Subject Qualifications

The ideal candidates for this sonar experiment are experienced naval sonar operators. The pool of experienced naval sonar operators is limited, however, and the recruitment of a sufficiently large number of experienced operators to yield statistically relevant results would be logistically challenging. Since this experiment is the first of a series of sonar experiments, it was deemed to be sufficient to use technically competent in-house personnel as operators, provided that the results of the experiment are understood in the correct context.

By using in-house personnel who are at least familiar with acoustics and/or have naval military training, it should be possible to obtain sufficient insight into the questions at hand and estimate the variance of the experimental results, so that maximal use could be made of the group of naval sonar operators in later, follow-on experiments.

Although this experiment makes use of a simulated maritime environment, that environment is not identical to the one aboard a present day naval vessel, and the tools and displays that are used are not the same as those used operationally. This may be an impediment to an experienced operator who is used to manually developing his or her own sonar tracks or making use of sonar information that would be available in a Lofargram display but not in the sonar track displays used in this experiment. In order to make best use of experienced naval sonar personnel, it is important to have a clear idea as to the number of personnel required, and to have subject matter experts evaluate the experiment to ensure that it is sufficiently challenging to warrant the additional logistics of bringing in a significant number of these limited personnel.

6.2 Approval for the use of Human Subjects

Defence R&D Canada (DRDC) requires that all experiments that involve human subjects be reviewed and approved by the Human Research Ethics Committee (HREC) at DRDC Toronto [5][15]. The approval process, traditionally associated with medical or physiological investigations, requires the preparation of a detailed research protocol and an interview with the committee. The aim of the HREC is to ensure that each experiment is held to a high ethical standard; that it is designed to make best use of the test subjects, is important enough to warrant use of human subjects, contributes to an

approved program, and produces results that cannot be obtained otherwise. The general requirement for review recognizes that the potential for harm to the human subjects is more than just physical and that maximum protection of subjects must therefore be ensured on a broader basis. HREC approval was obtained for VBE CA-1 in July 2003.

The HREC approved protocol for this experiment, Revised Protocol #L-416A, is in Annex E.

6.3 Subject Recruitment, Care, Handling and Remuneration

Volunteer subjects are to be recruited for this experiment through the use of the HREC-approved poster shown in Appendix A of Annex E. The subject time requirement is 7 hours in a single day. This includes training, morning and afternoon experimentation sessions and a debriefing with breaks and lunch time in between.

Voluntary consent forms and copies of the experimental protocol are provided to the subjects during the registration period. The consent forms require a witnessed signature as well as the signed approval of the Section Head or commanding officer of the subject. During the training session, the subject is instructed in the use of Horizon and provided an opportunity to interact with Horizon prior to the start of the experimentation sessions.

The morning and afternoon experimentation sessions are independent. During one session the subject will operate the Coalition Subject Station, during the other the subject will operate the Solo Subject Station. The debriefing session at the end of the day will provide an opportunity for the subject to respond to a questionnaire as well as providing free-form feedback on the experiment. The Run Director will also be present during the entire experiment to respond to questions and collect feedback from the subjects.

The level of confidence in the accuracy of the results of this experiment will depend on the variance of the results and the number of subjects completing experimentation runs. Since the variance of the results cannot be known in advance and cannot be reliably estimated using previous runs of the same or a similar experiment, it was decided to use eight operators initially and then use the results of those runs to estimate the number of subjects required in this and subsequent experiments.

The subjects are to be reimbursed a total of $27.64 for their participation in the experiment in accordance with the DRDC Toronto stress allowance schedule.

7. Experimentation Procedure

The experimentation sessions involving human subjects are held in the Virtual Combat Systems lab at DRDC Atlantic under the direction of a designated Run Director. For these sessions, the experimental apparatus in that lab is arranged as shown in Figure 7.

7.1 Test Sessions

Prior to the use of the volunteer subjects as operators, test runs of the experiment are used to validate the experimental process and infrastructure. The test runs are similar to the actual experimentation but typically included only those aspects of the experiment that still required validation. The training, for example, did not require significant modification and therefore only needed to be tested once. As well, since a member of the development team normally executed the test sessions, repeated training sessions were unnecessary once the training script had been established. The

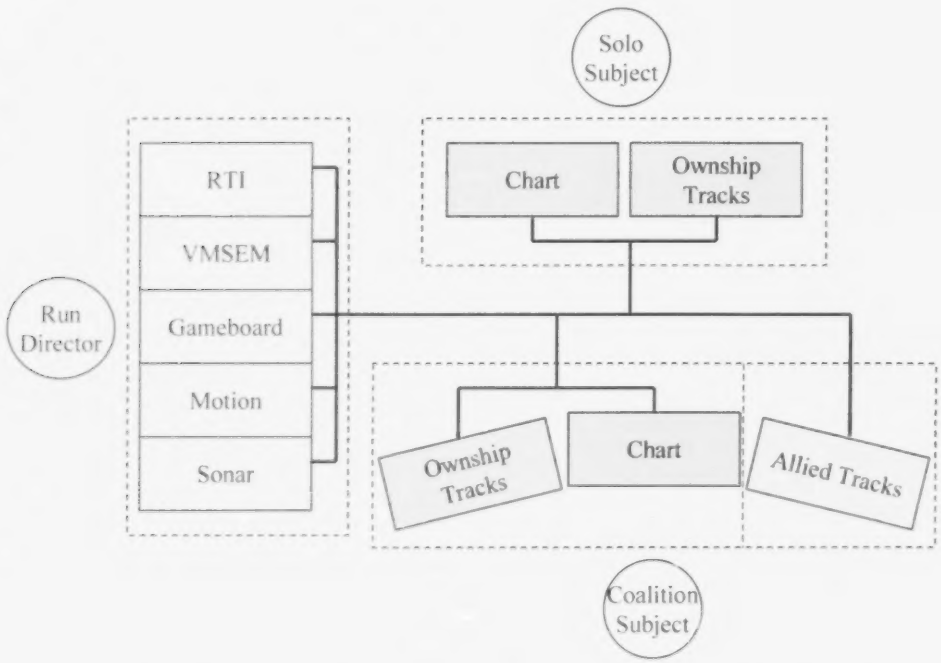

Figure 7. Physical layout and distribution of the experimentation infrastructure. Each dashed box represents a single computer. All subject displays are individual instances of Horizon.

test sessions use the designated test scenario, T1, that had been set aside for testing and demonstrations.

Several minor changes were made to address problems identified during testing sessions. Changes were made to the way in which both the state of the simulation and the responses of the operators to the simulation were recorded. Although the type, position and movement of the vessel traffic are predetermined in each scenario, the random fluctuations of the acoustic environment are not. Since the characteristics of the sonar track segments presented to the operator are dependent on the acoustic environment, these also vary among multiple runs of the same scenario. To facilitate the validation of the sonar and other federates and the analysis of the results of the experiment, additional fields were added to the log file generated by the sonar federate. Other logging devices, made redundant by the enhanced sonar log format, were removed. A description of the final sonar federate log file format is presented in Annex D.

The log files produced by each instance of Horizon record the local system time, not the simulation or federation time. In order to ensure that the local system time on all of the computers is synchronized, a requirement was added for the Run Director to execute JSS Clock Sync, a time synchronization utility, prior to each experimentation session.

The simulation time rate during the test sessions fell far short of the real-time performance originally expected. In order to bring the response closer to real-time, it was necessary to remove all software that was not essential to the operation of the simulation. This included Camtasia, the Virtual Maritime System Simulation Display (VMSSD) federate and our own VBE logger federate. Changes were also made to the way that the sonar federate waited between activity cycles. A similar modification was proposed for the other VMSA federates, some of which had been provided by external sources [4][12][20].

To improve performance, it was also necessary to adjust the way in which multiple instances of Horizon were initiated on the operator stations. Previous implementations of Horizon ran no more than one instance per computer and handled no more than a few tracks at a time. This experiment typically produces at least ten vessel tracks and several hundred sonar tracks.

These problems did not become apparent until the simulation was run for extended periods under heavy load. *Changes to the infrastructure configuration should not be made without further testing in order to ensure that the system will operate reliably when the subject operators are present.*

7.2 Conduct of the Experimentation Sessions

The Run Director is responsible for the execution of the experiment. In this role he or she provides background materials to the subjects, ensures that their consent forms are correctly completed, reads the training script and demonstrates the subject user

interfaces, responds to subject questions during the experiment, performs the exit interviews and documents the subjects' responses on the exit interview form. The Run Director is also responsible for starting, ending and monitoring the simulation system and, if necessary, adjusting the experimentation schedule to ensure the timely acquisition of accurate and reliable experimental data. Following each experimentation session, the Run Director is responsible for archiving the session log files.

The typical experimentation day schedule is shown in Table 3. The simulation can be started by following the first six steps shown in Annex A. The batch file used to initiate the simulation is also shown in Annex A. The training scenario, which can be run for up to 120 minutes, should be started about 20 minutes prior to the training session in order to provide a sufficient number of track segments at the start of the training session. The morning and afternoon experimentation sessions should not be started until the operators are prepared to begin.

Table 3. Typical subject session schedule

TIME	ACTIVITY
0900 - 0945	Subject registration and training
0945 - 1000	Morning break
1000 - 1200	Morning experimentation session
1200 – 1300	Lunch break
1300 - 1500	Afternoon experimentation session
1500 - 1515	Afternoon break
1515 - 1600	Exit interview

All of the scenarios are designed to finish in 120 minutes. By comparing the federation time shown on the VMSEM display on the Run Director Station with local system time, the Run Director can determine the progress of the simulation. The VMSEM display is shown in Figure 8. Should a scenario be slightly delayed, it is preferable to adjust the day's schedule to accommodate it, rather than dismissing the operators prior to the end of the scenario.

After the subjects have been provided with copies of the voluntary consent forms and other background material, the Run Director should proceed with the training session using the script shown in Annex B. Use of the training script ensures that the subjects are trained consistently and that all relevant issues are addressed. During the training session, the script should be read while the items being described are

Figure 8. The Virtual Maritime System Execution Manager Interface appears on the Run Director Station. Federation Time will begin to increment shortly after all of the indicated federates have joined the federation.

demonstrated. After the demonstrations the subjects should be given the opportunity to interact with the simulation.

To protect subject confidentiality, each subject will be assigned a random number between 0 and 99 by which their results will be recorded. The Run Director will record the number assignments, which are to be protected, as well as keeping a separate list of previously assigned numbers. References to session results will be by number only.

During the break between the training session and the morning experimentation session, the Run Director will terminate the training scenario and prepare either scenario 1 or scenario 4, with equal probability, for the morning session. The morning scenario should not be initiated until the subjects are ready to begin. The morning session will end when the experimentation scenario terminates. Following the morning session, the Run Director will preserve the results of the session by following step 10, the final step shown, in Annex A. The afternoon session should be run in a similar manner, using a different scenario than that used in the morning session. An example of a suitable sequence of subject positions and scenarios is shown in Table 4.

Table 4. *This is an example of a suitable scenario and position sequence. The subjects must alternate between the multiple scenarios and between the coalition and solo positions.*

SUBJECT NUMBER	SOLO SCENARIO	COALITION SCENARIO	POSITION SEQUENCE
1	1	4	CS
2	4	1	SC
3	1	4	CS
4	4	1	SC
5	1	4	CS
6	4	1	SC
7	1	4	CS
8	4	1	SC

During each experimentation session, the Run Director should observe the progress of the simulation and of the operators, and respond to any questions the operators may have. The Run Director should also ensure that the operators use only those interface tools discussed and permitted in the training session.

When the operators return from their afternoon break, they should be separately debriefed using the questions shown in Annex C. Before the subjects leave, the Run

Director should ensure that their voluntary consent forms have been correctly filled out and countersigned. Accurate contact information is also necessary in order for the subjects to be reimbursed for their time.

8. Data Analysis Plan

Following the execution of the experimental sessions, the log files produced by the sonar and Horizon federates and the EnterReason popup query, along with the results of the exit interviews and other subject and Run Director feedback are to be analyzed. The metrics to be used, both quantitative and qualitative, are described in the following section.

8.1 Analysis Criteria

8.1.1 Criteria for Quantitative Analysis

The first objective of this experiment is a comparison of two similar scenarios with and without the sharing of sonar data. A set of quantitative metrics is appropriate in this case in order to make clear and unambiguous comparisons between the results of the scenarios. The nature of this aspect of the experiment lends itself well to quantitative metrics as well, since the operator's task, the development of an operational picture from primitive sonar track segments, requires distinct and deliberate choices on the part of the operator. The metrics chosen and their derivation are described in the following section.

The metrics chosen to parameterize the level of operational picture development are similar, but not necessarily identical, to the metrics developed for use in other VBEs [8]. This larger set of metrics was collated and documented by DSTO and is largely based on the structure developed for the Single Integrated Air Picture Project (SIAP) to characterize picture quality [22]. Of particular interest in this sonar-only track association case are metrics related to picture clarity, track continuity, and track association, correctness, completeness and timeliness.

The metrics chosen are focussed on aspects understood to depend on the operator's level of comprehension. The task of the operator in this experiment is to identify sonar track segments that were believed to have originated from the same vessel and associate them into fused tracks. Clearly the comprehension of the operator will be reflected in the speed and accuracy with which those associations are formed as well as the completeness of the set of fused tracks.

Following the DSTO example, we define three types of tracks in this experiment:

1. A primitive track, also called a sonar track segment in this experiment, is developed directly by the sonar federate from sonar data and has no component tracks.

2. A composite track is a fused track made up of one or more primitive tracks and/or other composite tracks. Composite tracks are produced when the sonar operator uses the Active Fusion tool in Horizon to associate tracks.

3. A constructed track is a composite track that is not a component of any other composite track in the operational picture. It is a top-level track such as might be used for TMA.

It should be noted that, in this experiment, the sonar federates will produce at least one primitive track from each observed vessel during each experimental session.

Using these track types we define the quantitative metrics as follows.

8.1.1.1 Picture Clarity

Picture Clarity measures the number of constructed tracks relative to the number of primitive tracks.

$$\text{Picture Clarity} = \frac{\text{number of primitive tracks}}{\text{number of constructed tracks}}$$

Picture Clarity cannot decrease with the number of track associations regardless of whether the associations are correct or not since each association removes one or more primitive and/or composite tracks from the operational picture display and replaces them with a single constructed track. This metric is only valid for comparisons at a particular time, between pictures developed from similar scenarios. Comparisons should not be made between applications of this metric at differing times since, without operator intervention and with or without the generation of additional primitive tracks, picture clarity cannot decrease over time. This value does not reflect the accuracy of the track associations.

8.1.1.2 Track Continuity

Track Continuity measures the number of constructed tracks relative to the number of observed vessels. In this experiment, the number of observed vessels was the total number of vessels less one, for the observing vessel, since the sonar federate produced at least one primitive track from each observed vessel.

$$\text{Track Continuity} = \frac{\text{number of observed vessels}}{\text{number of constructed tracks}}$$

Track Continuity measures the average number of times that the track of each observed vessel appeared in the operational picture. In the ideally associated operational picture there would be only one track per observed vessel and this value would therefore be unity. The Track Continuity value decreases as those ideal tracks become more fractured. Since the accuracy of a target localization solution is related to the length and continuity of the track being analyzed, TMA is, in general, best supported by long, continuous sonar tracks. This value does not reflect the accuracy of the track associations.

8.1.1.3 Association Continuity

Association Continuity measures the number of disassociations made by the operator relative to the number of associations made by the operator.

$$\text{Association Continuity} = \frac{\text{number of disassociations made}}{\text{number of associations made}}$$

Association Continuity can be used to compare the relative confidence levels of operators within a given scenario or the relative complexity of scenarios developed by a given operator. It is not necessarily related to the number of constructed tracks as it may include pairs of primitive tracks that are repeatedly associated and disassociated. This value does not reflect the accuracy of the track associations.

8.1.1.4 Association Correctness

Association Correctness measures the number of correct associations made relative to the total number of associations made.

$$\text{Association Correctness} = \frac{\text{number of correct associations made}}{\text{number of associations made}}$$

Association Correctness can be used to evaluate the accuracy with which an operator makes track associations. Associations that are subsequently disassociated are considered to be corrections and are not included in this calculation.

8.1.1.5 Association Completeness

Association Completeness measures the number of correct associations made versus the total number of possible correct associations.

$$\text{Association Completeness} = \frac{\text{number of correct associations made}}{\text{number of possible correct associations}}$$

Association Completeness can be used to evaluate the completeness of the operational picture developed by the operator. This metric is calculated assuming that tracks are associated in pairs so that the number of possible associations is equal to the number of primitive tracks less the number of observable vessels. Associations that are subsequently disassociated are considered to be corrections and are not included in this calculation.

8.1.1.6 Association Delay

Association Delay measures the time lag between the initiation of a primitive sonar track and its inclusion in a composite track. If multiple primitive tracks are associated, the latest initiation time is used. If one or more composite tracks are included, the

track is decomposed into primitive tracks and the latest initiation time is used. The Association Delay is the sum of the time required for sufficient information to be available with which to make a decision, and the decision response time of the operator. The time required for sufficient information to become available may be quite significant, especially in complex scenarios where multiple observable targets appear at similar bearings. Either component can be factored out by comparing cases using either the same scenario or the same operator.

8.1.1.7 Measured Simulation Time Rate

The Measured Simulation Time Rate is the rate at which simulation time advances relative to real time.

$$\text{Measured Simulation Time Rate} = \frac{\text{elapsed simulation time}}{\text{elapsed real time}}$$

This value, which is measured from the start of the simulation, is a long-term average while the Actual Federation Rate shown on the VMSEM display is a short term average. In the VMSA this value would ideally be equal to the Desired Federation Rate but, due to the limitations of the simulation infrastructure, is usually somewhat less.

8.1.2 Criteria for Qualitative Analysis

The second objective of the experiment is aimed at uncovering the rationale used by a sonar operator in deciding whether to associate or disassociate groups of sonar tracks. The primary tool used to address this objective is a popup query that appears whenever the track association tool is used to associate or disassociate tracks. The exit interview, which uses the subject debriefing form shown in Annex C, offers a second opportunity to address this objective.

In both the popup query and the exit interview, the operator is presented with the opportunity to make a freeform response identifying aspects of the situation that the operator identifies as being significant to the decision process. As this is necessarily subjective, its analysis is not well addressed through the use of quantitative metrics. A catalogue and summary of the operator responses will be used. The query popup is not entirely freeform, as it also offered the subject a number of prepared responses from which to choose. The distribution of these choices is also of interest.

9. Data Collection Plan

9.1 Data Requirements

Implementation of the Data Analysis Plan described in the previous chapter will require that particular pieces of data be collected during each experimentation session. Some of this data, which is generic with respect to operator but particular to the session, can be collected at the Run Director Station, while other data is particular to the operator and should be collected at each operator station.

Each experimentation session will execute one of the prepared scenarios. It is essential that the Run Director record the number of the scenario used for each session.

The sonar federate produces a text format log file. Each instance of Horizon produces two log files, one in text format and the other in binary format. The format of each of the text format files is shown in Annex D.

9.1.1 Picture Clarity

The requirements of the Picture Clarity metric can be met by extracting the number of primitive tracks from the sonar log file and the number of constructed tracks from each Horizon log file. Horizon names each track from a particular sensor consecutively. As a result, the number of primitive tracks from a sonar is equal to the highest primary track number from that sonar.

The number of constructed tracks is not necessarily equal to the value of the highest composite track number since a constructed track can include composite tracks. For example as shown in Figure 9, if composite track F1 is made up of primitive tracks P1 and P2, then F1 will be a constructed track as long as F1 is not disassociated and is not a component of any other composite track. If composite track F1 is associated with primitive track P3 to form composite track F2, then track F1 will no longer be a component of any other composite track. If composite track F1 is associated with

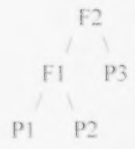

Figure 9. Track nomenclature. P1, P2 and P3 are primitive tracks, and F1 and F2 are composite tracks, but only F2 is a constructed track because it is not a component of a composite track.

primitive track P3 to form composite track F2, then track F1 will no longer be a constructed track since it is a component of composite track F2. F2 would then be a constructed track so long as it is not disassociated and is not a component of any other composite track. The association and disassociation of tracks is recorded in the Horizon log files.

9.1.2 Track Continuity

The requirements of the Track Continuity metric can be met by extracting the number of observed vessels from the sonar log file or the scenario file, and the number of constructed tracks from the Horizon log file.

9.1.3 Association Continuity

The requirements of the Association Continuity metric can be met by extracting the number of associations and disassociations made from the Horizon log file. Although association events are not recorded in the Horizon text log file, the subsequent appearance of a new composite track, specified with its component tracks, can be used to reconstruct the association decision. Similarly, the logging of a track that had previously been a component of a composite track can be used to reconstruct a disassociation decision.

9.1.4 Association Correctness

The requirements of the Association Correctness metric can be met by extracting the number of associations and the components of each composite track from the Horizon log file. The number of correct associations can be determined by relating each primitive track to the vessel or vessels from which it was produced and ensuring that these vessels are consistent. The relationship between the primitive track segments and the source vessels can be found in the sonar log file. This may be ambiguous when multiple vessels at a similar bearing produce a single primitive track representing them as a group. An additional test of a correct association is that all of the component tracks must be consecutive in time.

9.1.5 Association Completeness

The requirements of the Association Completeness metric can be met by extracting the number of possible correct associations from the sonar log file. The number of possible correct associations can be developed from the number of primitive tracks relating to the vessel in question. The number of correct associations can be determined as described in the previous paragraph.

9.1.6 Association Delay

The requirements of the Association Delay metric can be met by extracting the association time of each composite track from the Horizon log file and the initiation

time of each of its primitive track components from the sonar log file. Those components that are composite tracks should be further reduced to primitive tracks before an evaluation is made.

9.1.7 Measured Simulation Time Rate

The requirements for the Measured Simulation Time Rate can be met by extracting the initiation times of the primary tracks from both the sonar log file and the Horizon log file. The sonar log is recorded in federation time while the Horizon log is recorded in system time. Elapsed time in each time-space can be determined by the difference between the initiation time of the first primary track and the most recently initiated primary track. If the simulation exhibits slower than real-time performance, the elapsed federation time will be increasingly less than the elapsed system time.

9.1.8 Requirements for Qualitative Analysis

The EnterReason popup query produces a log text file. The file contains a numbered list of possible rationales for an association or disassociation decision followed by the system times at which each decision was made, the type of decision, and the decision rationale offered by the operator.

The requirement for Qualitative Analysis can be met by compiling and analyzing the EnterReason log file, the results of the exit interview, and other comments made by the operators.

9.2 Recording the Results of an Experimentation Session

The Run Director is responsible for adequately preserving the results of each experimentation session. This is done by following the final step in the Experimentation Software Setup procedure shown in Annex A, which will copy the sonar, Horizon and EnterReason log files to a unique directory on the shared drive of the Run Director Station. The Run Director must also record the station used, either solo or coalition, and the scenario seen by each operator. The operators should be indicated by subject number only, not by name.

The Run Director is responsible for maintaining a backup copy of the shared drive containing the experimentation software and the results to date. This is facilitated by good experiment design, as in the current experimentation configuration, where all of this material is on drive v: of the Run Director Station, shared to the other stations, and then remotely mounted on each station as drive v.

It is not strictly necessary that sufficient information be preserved to exactly repeat the experiment. To do so would be especially challenging since the variability of the sonar tracks is due in part to the influence of noise calculated using a random number generator. It is sufficient that enough information be preserved to permit later testing for correct operation of the experiment from the perspective of the operator. This can

be done while analysing the results of the experiment. A successful experiment is one in which the experimental objectives are met and the experimentation sessions proceed as described in the conceptual model.

10. Distribution of the Experimental Results

Successful completion of this experiment will include the production of a number of documents to describe the context, process, operation, results and conclusions of the experiment.

1. This experimental plan is intended to provide some context for the experiment as well as a blueprint and guide for the implementation and execution of the VBE CA-1 experiment. It will be published as a DRDC Atlantic Technical Memorandum.

2. An HREC protocol document was produced as part of the HREC review process. A copy of the protocol as approved is included as Annex E to this experimental plan. Following the completion of this experiment, a letter will be sent to the HREC indicating the number of operator subjects that would be required for a follow-on experiment involving experienced naval sonar operators. The voluntary consent forms obtained in this experiment must also be submitted to the HREC.

3. A pair of DRDC Atlantic Technical Memoranda will be produced following the experiment to describe it from both a scientific perspective and an implementation perspective. The scientific paper will discuss the motivation and rationale for the experiment, and present an analysis of the results along with conclusions pertinent to the experimental objectives. The implementation paper will focus on the mechanics of the experiment and is intended to be of greatest interest to personnel involved in the performance and execution of experiments using a similar experimentation infrastructure. These papers will constitute the primary record of the experiment.

4. A number of shorter papers and presentations will present a synopsis of the experiment to external audiences from a perspective appropriate to the target audience. These include presentations and papers to TTCP MAR TP-1 and The 9th International Command and Control Research and Technology Symposium.

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Annex A Experiment Software Setup

To run the experiment using the experimentation configuration described here:

1. Log into the computers *Run Director* (Archer), *Operator 1 Ownship* (Cherokee), *Operator 1 Allied* (Seneca) and *Operator 2* (Piper). Use the *vbe user* account on the Operator machines.

2. On each of the computers, click on the *Synchronize* button in the JSS Clock Sync window. Then click on the *Exit* button in the same window to close this application.

3. Select the scenario to be run by editing *V:\VBE CA-1\VMSA\bin\Start Gamboard.bat*. The full path name of the scenario file must be shown in quotes immediately after the word "Gameboard" on the line beginning with "Gameboard".

4. On the Run Director computer, execute the batch file *Run Director – 2 operators*. On the Operator 1 Ownship computer, execute the batch file *Operator 1 – Ownship*. On the Operator 1 Allied computer, execute the batch file *Operator 1 – Allied ship*. On the Operator 2 computer, execute the batch file *Operator 2*. In all cases, the batch files can be found on the desktop or in the *V:\VBE_CA-1\bin* folder.

5. The execution manager, VMSEM, will appear on the Run Director display. The federation will not start until about two minutes after all of the federates show *True* in the *Joined* column. Experiment progress, including federation time in seconds, is shown on the Execution Manager.

6. The Operator 1 Allied computer represents the allied vessel. Maximize the Horizon window, then click on the TBRG button to select the time-bearing display. Click on the 30 button to set the display to show 30 minutes of data. Maximize the Enter Reason application, center it in the track display and then minimize it.

7. The Operator 1 Ownship and Operator 2 computers represent the ownship. On each computer, drag the Horizon display without the active fusion plug-in onto the rightmost monitor, maximize it then click on the MAP button to select the chart display. Click on the Ownship button to center the display on the ownship and on the 100K button to show a 100 km ring around the ownship. Maximize the remaining Horizon display on the leftmost monitor, then click on the TBRG button to select the time bearing display. Click on the 30 button to set the display to show 30 minutes of data. Maximize the Enter Reason application, center it in the track display and then minimize it.

8. Seat the operators and run the experiment.

9. To end the experiment, close each of the program windows on each computer.

10. Following the experiment, create a new directory under the *V:\Log files* folder and rename it to reflect the date and time of the experiment. Copy configuration and log files into this folder as follows:

    a. Copy the sonar log files *sonar.cfg* and *sonar.log* from *V:\VBE_CA-1\VMSA\federates\Sonar\bin* into the primary folder.

    b. Copy the reasons logging file from *C:\reasons\file* on the Operator 1 Ownship computer as *reasons_coalition_ownship.txt*.

    c. Copy the Horizon text logger file from *C:\ text_log_files* on the Operator 1 Ownship computer as *horizon_coalition_ownship.log*.

    d. Copy the Horizon binary logger file from *C:\ binary_log_files* on the Operator 1 Ownship computer as *horizon_coalition_ownship.dat*.

    e. Copy the reasons logging file from *C:\reasons\file* on the Operator 1 Allied computer as *reasons_coalition_allied.txt*.

    f. Copy the Horizon text logger file from *C:\ text_log_files* on the Operator 1 Allied computer as *horizon_coalition_ownship.log*.

    g. Copy the Horizon binary logger file from *C:\ binary_log_files* on the Operator 1 Allied computer as *horizon_coalition_allied.dat*.

    h. Copy the reasons logging file from *C:\reasons\file* on the Operator 2 computer as *reasons_solo_ownship.txt*.

    i. Copy the Horizon text logger file from *C:\ text_log_files* on the Operator 2 computer as *horizon_solo_ownship.log*.

    j. Copy the Horizon binary logger file from *C:\ binary_log_files* on the Operator 2 computer as *horizon_solo_ownship.dat*.

```
@echo This script will set up the Run Director's
position in a 2 operator federation.
@echo.
@echo Press Ctrl-C to exit now or
@pause

cd /d v:\vbe_ca-1\vmsa\bin

start /MIN "RTI" "Start RTI.bat"
start /MIN "RTI Console" "Start RTI console.bat"

start /MIN "VMSEM" "Start VMSEM.bat"
start /MIN "Motion" "Start Generic Motion.bat"
start /MIN "Gameboard" "Start GameBoard.bat"
start /MIN "Sonar" "Start Sonar.bat"

@rem start /MIN "Horizon Allied" "Start
Horizon_allied.bat"
@rem start /MIN "Horizon Own" "Start Horizon_own.bat"
@rem start /MIN "Horizon Own2" "Start Horizon_own2.bat"
@rem start /MIN "Horizon Own3" "Start Horizon_own3.bat"
@rem start /MIN "Horizon Own4" "Start Horizon_own4.bat"
@rem start /MIN "Reasons" "c:\EnterReasons.exe"
```

Figure 10: This batch file, Run Director – 2 Operators, is used at the Run Director Station to initiate the simulation. Similar, appropriately modified batch files are used on the other computers.

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Annex B Subject Training Scripts

The following points should be covered with the experiment subjects.

B.1 Introduction

In this simulation, you will be acting as the sonar operator aboard a frigate that is using a towed array sonar to monitor vessel traffic in a narrow strait. The position of the ownship in the strait is shown in the navigational chart display on the center screen. An allied ship using a similar towed array sonar may be available to assist you by providing a copy of its sonar tracks. The position of the allied vessel is also shown in the navigational display. No other information about vessel traffic in the strait is available. The task of the operator is to develop as complete of a local operational picture as possible. Operational picture quality is determined by the clarity of the ownship track display.

The number and course of the vessels in the strait is unknown, although each vessel has an acoustic signature that can cause track segments to appear on the passive sonar display. The nature of the targets, the local environment and the sonar system are such that the there is only direct path propagation, i.e. a vessel can produce no more than one track segment at a time. A track segment may be terminated for a number of reasons including target range, high background noise or interfering signals. There is no restriction on the number of times that the track of a vessel may be terminated and reinitiated. Without track association, the sonar system will interpret each track segment as a unique and unrelated piece of information.

Target motion analysis (TMA) which can be used to derive target position estimates from bearing estimates, is strongly affected by the duration and completeness of the track being analyzed. Therefore, correctly associating multiple track segments into a longer, more complete master track will greatly improve the accuracy of the target position estimate.

A tool is available to associate track segments that are believed to have originated from the same source. The same tool can also be used to disassociate fused tracks back into their original segments. One of the objectives of this experiment is to investigate the process by which an operator decides to associate or disassociate tracks and so a popup menu will appear whenever the association tool is used. The tool will ask the operator to either select a reason for the decision from a checklist or enter it in a text box. It is important that your selection accurately represents the reasoning you used to make the association or disassociation decision. The text box option should be used if you don't see your reason in the checklist. This is a key part of the experiment.

During the following description of the simulation interface you are encouraged to operate the tools and features after they are discussed. Ask the Run Director if you have any questions about the simulation or the controls. Please do not use any controls

other than those indicated by the Run Director. If you would like to make use of a feature that is not available or has not been explained, please ask the Run Director for assistance at any time.

B.2 The Navigational Chart Display

The navigational chart displays the navigable waters in the region of interest. The ownship and allied ship are shown here as grey arrows labelled Ownship and AS_Vessel respectively. The range rings are labelled in kilometres. Yellow labels on the periphery of the range rings indicate ownship track labels but will not be used in this experiment, as they will quickly become illegible.

The Ownship button can be used to center the chart on the ownship.

The Lat/Long button can be used to center the chart on an arbitrary point by clicking on the button and then on that point.

The Object button can be used to center the chart on the allied ship by clicking on the button and then on the allied ship.

The 5K, 10K, 20K, 50K or 100K buttons can be used to change the map scale.

Using a mouse button to indicate a box on the chart will cause it to zoom in on that box. Clicking the right mouse button on the chart will cause it to return to the last button-selected scale.

The cursor position is shown in the lower right corner as range, bearing from the center and as latitude, longitude.

B.3 The Sonar Track Display

The sonar display shows sonar tracks for a specific ship in time-bearing format. Each sonar track segment is drawn as a series of open circles followed by a question mark. The ship's course is indicated as a series of solid grey circles. Plot time is shown in HH:MM format and bearing is shown in degrees absolute.

The cursor position is shown in the lower right corner as time and bearing.

The Active Fusion tool in the lower left can be used to associate track segments into fused tracks. Begin by clicking on the Select Tracks button until it is green and the Selected Tracks window above it is empty. Track segments in the time-bearing plot can be selected by left-clicking on them. They will change to bold and appear in the Selected Tracks window when they are selected. If the mouse-click is ambiguous, a checklist of track segments near the click position will appear. Track segments that are selected will have a checkmark next to them. Highlight and click on a segment to toggle its selection.

Dragging the left mouse button across an area of the screen will cause the display to zoom in on the selected area. Clicking the right mouse button on the display will cause the display to return to full-scale.

To associate the tracks shown in the Selected Tracks window into a single fused track using the Combine All Tracks method, click on the green checkmark button. The selected tracks will be removed from the time-bearing plot and replaced with a single track drawn as a series of lightning bolts followed by a question mark.

Whenever the green checkmark button is clicked, a popup window appears asking why that choice was made. To respond, click on the button beside the best response. If the button for the "other" response is selected, a text box will appear in which to describe the "other" reason. Click on "OK" after a reason has been entered and the popup window will disappear.

To disassociate a fused track, select it then click on the red "X" button. The fused track will be removed from the plot and the original track segments will reappear. Clicking on the red "X" button will also cause the popup menu to appear. Click on "OK" after a reason has been entered and the popup window will disappear.

The Annotation Generator tool in the lower middle can be used to annotate tracks. Begin by selecting the track to be labelled in the box labelled Associated Track. Only those tracks shown on the corresponding plot above can be annotated. For the Ownship, these track labels begin with CA_Sonar, for the allied ship, these track labels begin with AS_Vessel. Having selected a track, enter the annotation in the box labelled Annotation Text. In the box labelled Age (seconds) enter the number of seconds that have elapsed since the desired annotation time. When the Create button is clicked, an annotation will appear next to the specified track at the specified time. As time advances and the display scrolls down, so will the annotation. Annotations made to track "<none>" will appear on the right side of the time-bearing plot.

Annotations can be placed at an arbitrary location in the time-bearing plot by specifying the coordinates of the location in the Bearing and Age boxes. Make certain that the Bearing Valid box is checked when using this option and unchecked when locating by track.

The Annotation Maintenance tool in the lower middle can be used to alter annotations. Begin by clicking on the Select Annotations button until it is green, then left-click on the annotation to be altered or select it from the drop-down menu in the box labelled Annotation. The annotation text can be edited in the box labelled Text and the track to which it is attached can be altered in the box labelled Track. Click on Modify to update the annotation or Delete to delete it.

Clicking on the Fused and Sonar buttons in the top left corner will turn those tracks off (yellow) and on (green).

Clicking on the Notes button in the top left corner will turn track annotations off (yellow) and on (green).

The time duration of the display can be selected using the 30, 60 and 90 minute buttons on the middle left side of the display.

The center of the bearing axis of the display can be toggled between 0° and 180° by clicking on the Shift 180° button on the middle right side of the display.

No other controls will be needed in this experiment. Please ask the Run Director for assistance before operating any other controls. Please take some time now to exercise those controls that have just been described.

Annex C Subject Debriefing Form

Ask the subject the following questions and record the responses and any additional comments.

1. How do you know about sonar? How many years of experience do you have?
2. What is your practical experience with sonar data? How many years of experience do you have?
3. How satisfied were you with the local operating picture that you developed?
4. What use did you make of the allied ship display?
5. How would you rank the value of the allied ship tracks in your development of the local operating picture (high, medium, low)?
6. What additional controls or tools would you have liked to have had?
7. Any other comments?

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Annex D Log File Formats

D.1 Horizon Log File Format

The Horizon log file format is shown in Table 5. The data is comma delimited with an update interval of 15 seconds. A separate line is required for each track update.

Table 5. *Horizon log file format.*

Field	*Type*	*Description*	*Precision*	*Invalid Value*
System Time	String	System Time (hh:mm:ss AM/PM)		
Data Time	String	Time at which the data was recorded (hh:mm:ss AM/PM)		
Composite Tracks	String	Zero or more strings in the format of the Track Number field and separated by the '/' character that identify the member tracks of an association		
Track Number	String	Provides a unique track identification in the form <Horizon data source>:< track ID>		
Master ID	String	Track master ID as set by the operator, otherwise blank.		
Latitude	Float	Latitude in decimal degrees	0.0001	-999.999
Longitude	Float	Longitude in decimal degrees	0.0001	-999.999
Error_Major	Float	Semi-major axis of the ellipse that forms the area of uncertainty	0.1	-1.0
Error_Minor	Float	Semi-Minor axis of the ellipse that forms the area of uncertainty	0.1	-1.0
Error_Angle	Float	Degrees from vertical of the ellipse that forms the area of uncertainty	0.1	-1.0
Course	Float	Degrees [0-360)	0.1	-1.0
Speed	Float	m/s	0.1	-1.0
Source ID	String	Name of the source platform that is providing the track data		
Source Latitude	Float	Latitude in decimal degrees of the source platform at data time	0.001	-999.999
Source Longitude	Float	Longitude in decimal degrees of the source platform at data time	0.001	-999.999
Bearing	Float	Absolute bearing in degrees [0-360) from the source platform to the track	0.1	-1.0

D.2 Sonar Log File Format

The Sonar log file format is shown in Table 6. The data is tab delimited with an specifiable update interval, typically 5 seconds. A separate line is required for each track update.

Table 6. *Sonar log file format*

Field	*Type*	*Description*	*Precision*	*Note*
Type Code	Integer	101 (initiate new track), 201 (update existing track), or 301 (terminate track).		
Track Name	String	Name of the source that is providing the track data.		
Track Number	Integer	Unique sequential identification number for this track from this source.		
Time Step	Integer	Federation time step at which the track update occurred		
Bearing	Float	Absolute bearing of the centroid of the acoustic source(s) (degrees).	0.0001	type codes 101 and 201 only
Range	Float	Range of the centroid of the acoustic source(s) (km).	0.0001	type codes 101 and 201 only
Signal Excess	Float	Signal excess of the received acoustic signal (dB).	0.0001	type codes 101 and 201 only
Target Count	Integer	Number of acoustic emitters represented by this track.		type codes 101 and 201 only
Target Name(s)	String	Name(s) of the acoustic emitters represented by this track		type codes 101 and 201 only

Annex E The HREC-Approved Protocol for VBE CA-1

Protocol: L-416A

Title: Coalition passive sonar track sharing and association

Principal Investigator: Garfield R. Mellema, DRDC Atlantic
Co-Investigator: Tania E. Wentzell, DRDC Atlantic

DRDC Thrust: 11cs / 11bk

Executive Summary

The ability to exchange tactical information among coalition partners has the potential to significantly improve our ability to conduct underwater warfare. The degree of improvement, however, is dependent on the rate at which the information can be transferred between partners as well as their ability to process the received data. In a typical scenario, as sensor information is processed into target location, course and speed, the data volume decreases dramatically while the transmission delay increases. In some cases it may be worthwhile to trade off data volume to minimize transmission delay. Some of the more sophisticated processing techniques such as cross-correlation or triangulation, which extract time or location information from comparisons of low level data from multiple sensors, would not be available without this shared data.

In order to benefit from shared data, the recipient must be able to receive and process it to derive added value with sufficient speed to justify the increased cost of transmitting it at a low level. Otherwise, it would be better to process it at the source and send only the processed data. Although data exchange issues that are related to automated systems, such as bandwidth or processing speed, can usually be clearly specified, issues related to the human operator may be more difficult to define. The minimum level at which data exchange is beneficial may be masked by issues more related to operator loading than to operator comprehension.

This experiment will investigate the value of sharing sonar data at a low level of development between the operator's own ship and a geographically remote allied vessel. The outcome of this experiment will be determined by measuring the quality of the local operating picture developed by the operator on board the own shi

A single acoustic source in the local environment may cause multiple sonar track segments to appear on a sonar screen, each represented to the sonar operator as a potentially unique target. These track segments may be separated in bearing due to differing propagation paths between the source and receiver, and / or separated in time due to changes in the source level, source or receiver location or the local environment. Multiple sonar track segments that are believed to have originated from the same source can be grouped into a master track in spite of their differences in time, frequency or bearing. This track association process is very labour intensive and relies heavily on the sonar operator's training and experience.

Automation of this task is desirable, as is insight into the decision process used by human operators to decide whether or not to associate track segments.

In this experiment, the subject will be asked to develop a local operational picture indicating the number and actions of nearby vessels. The subject will be supplied with information about the local environment and the positions of the own and allied ships as well as track information from the own ship sonar display. Comparisons will be made between local operational pictures developed with and without the benefit of additional sonar track information from the allied ship. Measurements will also be made of the number and quality of track association and disassociation decisions made by the subject and the logic behind those decisions as they are made. The subjects will be further debriefed in a follow-up interview.

This experiment presents minimal risk to the test subjects. No psychological measures will be taken and no emotionally distressing stimuli will be used. There is a risk of eyestrain and fatigue associated with viewing a computer monitor and operating a computer keyboard and mouse. Participants will participate in one seven hour experiment with three breaks and will be reimbursed appropriately.

Protocol: #L-416A

Title: Coalition passive sonar track sharing and association

Principal Investigator: Garfield R. Mellema, DRDC Atlantic
Co-Investigator: Tania E. Wentzell, DRDC Atlantic

Background

Coalition Data Exchange

Information exchange among coalition partners has the potential to provide significant advantages in the execution of underwater warfare. The degree to which that potential is realized, however, may be dependent on the available bandwidth between the platforms and their ability to process the received data. As sensor data is refined from sound pressure to target location, course and speed, the data volume decreases and its information content increases. One cost is latency. Another is the lost opportunity to undertake lower-level multi-sensor processing, such as cross-correlation or triangulation.

Exchanging sensor-level sonar data entails its own set of costs and complexities. High bandwidth connections as well as powerful and sophisticated processing techniques are essential to the successful utilization of multiple streams of sensor-level data. In return one gains the capability to significantly reduce the time required to achieve target localization and identification. The payoff is not infinite however, as at some level the costs of increased data sharing outweigh the additional benefits. In order to make a good decision as to the most appropriate level at which to share data between platforms, one needs a sense of how these costs and benefits trade off.

The minimum level at which it is beneficial to share data depends strongly on the speed and sophistication of the data processing available at the source, and the input requirements of the processing routines at the recipient. Although the minimum input level of an automated processing system may have been clearly specified, in the case of a human operator the minimum beneficial input level may be more difficult to identify, as it may be masked by issues related more to operator loading than to operator comprehension.

Investigating the potential benefits of low-level sonar data exchange requires the examination of the results of a series of scenarios in which sonar data at differing levels of development are provided to the ownship[4] from a geographically remote allied vessel. The value of these results will be assessed in terms of the quality of development of the local operating picture. The experiment described in this document is the first in a series of experiments aimed at implementing this process.

Passive Sonar Track Association

A single target vessel will typically produce acoustic emissions at multiple frequencies. These signals may propagate along multiple paths to a receiver and may be intermittent in time due to such external influences as variations in source or receiver location

[4] Ownship is a commonly used naval term to indicate 'our own ship', that is, the vessel that is controlled by the subject.

or the local environment. Each emission is eventually represented to the sonar operator as a signal track segment from a potentially unique source.

Passive sonar association is the process of associating signal track segments across time, frequency and/or bearing into master tracks that are common to a single source vessel. Although rudimentary tools exist to assist the operator in this task, it can be very labour intensive and relies heavily on the operator's training and experience. The use of an automated passive sonar association system or aid has the potential to improve situational awareness in the underwater environment and reduce the response time to threats by increasing the effectiveness of the human operator.

If one has knowledge of the local environment, the locations of a source and a receiver and the source level, it can be fairly straightforward to calculate the sonar track segments that would result. The inverse is not necessarily true, as it can be extremely difficult to reliably determine whether apparent relationships between multiple track segments correspond to a common origin.

In order to provide some insight into potential processes for automated track segment association, a better understanding of the decision process by which a human operator decides whether or not to associate track segments is required. The experiment described in this document is the first in a series of experiments aimed at investigating that process.

Purpose

Data exchange among coalition partners can take place at multiple levels of refinement. While highly refined data may require little additional processing by the operator, low-level data may contain information lost in the refinement process. Deciding at which level to exchange data requires an understanding of the value of the differing levels of data to the recipient. One goal of the experimentation campaign, of which this is the first experiment, is to investigate how the value of coalition data sharing changes as the exchanged data becomes increasingly refined. This experiment will provide a baseline for comparison, by contrasting local operating picture development in the cases of a single sonar operating alone, and with shared bearings-only sonar tracks from an allied vessel.

Tracks developed from sonar sensor data can exhibit discontinuities due to such conditions as apparently erratic movement of the target or a temporary reduction of the signal to noise ratio of the target below the system detection threshold. The track segments preceding and following the discontinuity share a common origin and therefore merit association into a common master track, but it is difficult for an automated system to accurately and reliably identify such segment pairs in spite of their apparently similar characteristics. A second goal of this experiment is to investigate the decision-making process used by the operator to decide which track segments to associate or disassociate and when to do so. This information will provide insight into potential algorithms for automated track association and a benchmark for evaluating the effectiveness of automated track association techniques.

Prior to the main experiment, a pilot experiment will be executed, the objective of which is to ensure the suitability and effectiveness of the process and procedures used in the main experiment.

Selection of Subjects

The pilot experiment will be held at DRDC Atlantic. Participants will be DRDC Atlantic employees, preferably Navy personnel familiar with naval sonar. They will be recruited using the poster in Appendix A distributed by email or posted at DRDC Atlantic. Twelve participants will be used in order to establish the variance of the measurement process.

The main experiment will also be held at DRDC Atlantic. Participants will be Navy personnel familiar with naval sonar, recruited from the Canadian Forces Naval Operations School (CFNOS) in Halifax. They will be recruited using a poster distributed by email or posted at CFNOS. The number of participants, which will be determined by the variance of the results of the pilot experiment, is anticipated to be between 12 and 20.

Participants in both the pilot and main experiment will be limited to those between 18 and 65 years of age and self-selected to have normal or corrected to normal vision. Although this study is gender neutral, the subject gender ratio is anticipated to reflect the demographics of the group from which the subjects are recruited.

Methodology

Apparatus

The study will be conducted in an office under normal lighting conditions. The subject will be seated in an office chair in front of a computer table. In the first configuration, a keyboard, mouse and a 17" flat-panel display will allow the operator to interact with a computer running an interactive simulation of a maritime environment. In a second configuration, an additional 17" flat panel display is added, along with a second keyboard and mouse. These will allow the operator to interact with a second computer that is running additional components of the maritime simulation.

Stimuli

The operator is presented with a chart display showing the navigable boundaries of a narrow strait and indicating the position of his own ship as well as that of an allied vessel as shown in Figure 11. The ownship is following a predetermined course at predetermined speeds appropriate for the operator tasking. No other information about other vessel traffic in the strait is available from the chart display. Passive sonar is being used to monitor all vessel traffic in the strait, and the sonar tracks are available as plots of bearing versus time as shown in Figure 12. The sonar tracks corresponding to the target vessels are disjoint in time, due to variations in the environment and the acoustic source level of each target as well as interference from other acoustic sources. The relationship between each target and its one or more representative track segments is indistinct, due primarily to the lack of immediate range information from the passive sonar system. In the second configuration, passive sonar track information in a similar format is available from a sensor aboard the allied vessel and shown on the leftmost screen.

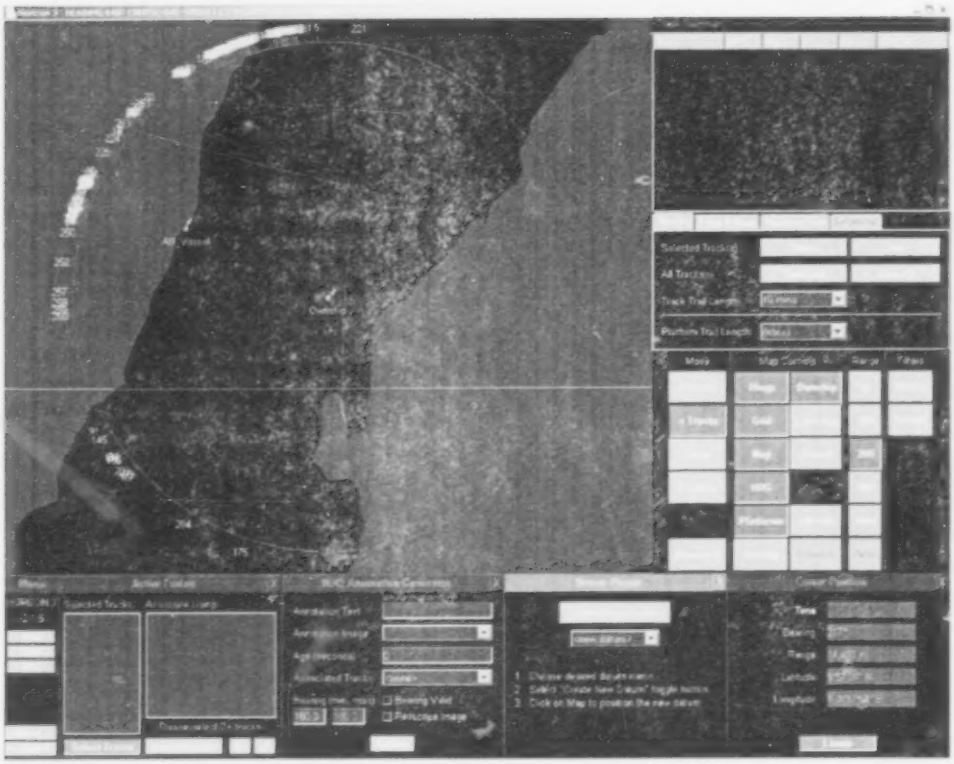

Figure 11 Ownship chart display

Task

The task of the operator is to develop an operational picture of vessel traffic in the strait using only knowledge of the strait and of own and allied ship positions from the chart display and passive sonar track information from the track displays. In order to refine the ownship track display, the operator can associate multiple track segments that are believed to have originated from the same target vessel into a master track. Similarly, the operator may disassociate a master track back into its original track segments should it be concluded that their association was without merit. An ideally developed track display would present a single continuous track for each target vessel for the entire time that it is within detection range of the ownship sonar. In the second configuration, when passive sonar track information is available from the allied vessel, the additional, nonorganic track segments may be associated amongst themselves and the results observed by the operator, but cannot be electronically communicated onto the ownship display or associated with the organic track data. The level of development of the ownship track display will determine operational picture quality.

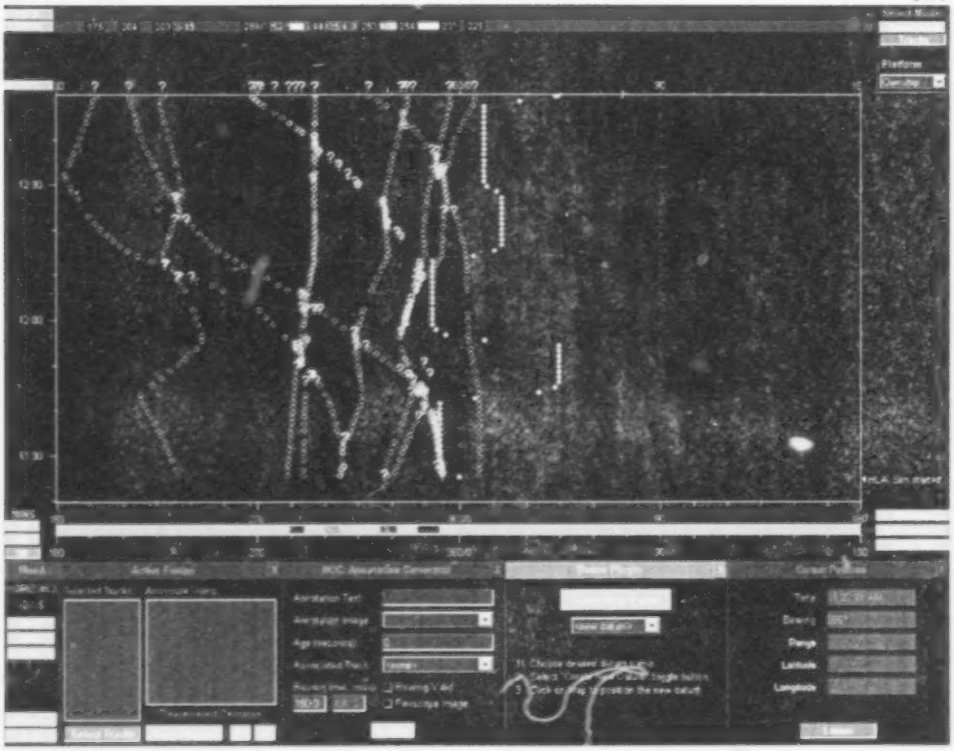

Figure 12 Ownship passive sonar track display

With few exceptions, all operator interaction with the simulation can be performed using only the mouse. Changes to the scale of the chart display can be done using the mouse, as can changes to the time or bearing scale of the track display. Track segments on a track display can be associated into a fused master track by using the mouse to select the component segments and then clicking a checkmark icon within the track association module. Clicking on a corresponding "X" icon will disassociate a selected master track.

Following either an association or a disassociation action, the operator will be queried by a popup menu as to the cognitive process that led to the association or disassociation decision. The operator will be asked to indicate the rationale that led to the decision from a prepared list or provide an alternate rationale. A sample of the initial list of prepared rationale to be used in the pilot experiment is shown in Table 7. The list to be used in the main experiment will be developed from the results of the pilot experiment. The subject will be supervised at all times.

1. Bearing continuity
2. Signal strength
3. Operational constraints of the target vessel
4. Operational constraints of the water space
5. Navigational procedures
6. Other (specify)

Table 7 Initial list of prepared rationales for track association or disassociation.

Procedure

All of the scenarios in this experiment take place in the same strait, but may differ in the number, course and speeds of the target vessels; the course and speeds of the own and allied ships; and the ability to share sonar data with the allied ship.

The experiment will begin with a training session in which the operator is introduced to the simulation system and the two types of scenarios. During this training session, the operator will be introduced to the navigational chart of the strait, and to the ownship and allied ship sonar track displays. The controls to modify the resolution of the screen displays will be demonstrated, as will the controls to associate and disassociate track segments. The operator will then have the opportunity to interact with a version of the second experimental configuration, i.e. including shared data from the allied ship, which differs from the testing versions. The total time allocated for subject training is one hour. Prior to the training, the subject will be asked to sign the consent form in Appendix B.

Following operator training and familiarization, the subject will participate in two testing sessions employing the methodology described above. Each subject will interact with both the independent and coalition simulations, in random order. Each simulation will last about two hours.

A closing interview will follow the simulations. During the interview, the results of the test may be discussed with the subject. They will be asked to describe the cues they thought to be useful in deciding what to associate or disassociate and when to do so. These cues may be added to later versions of the (dis)association rationale checklist. The subject will also be asked to describe his perception of the value of the sonar tracks shared by the allied vessel. The interview is estimated to last about one half hour.

Analysis

Quantitative Analysis

The level of development of the local operating picture will be evaluated based on the number and configuration of tracks on the ownship track display. Four measures will be used.

1. **Clarity** measures the number of displayed tracks relative to the number of track segments available to be displayed. Recall that association replaces multiple track segments from the display and replaces them with a single master track.
2. **Completeness** measures the number of correct associations made versus the total number of possible correct associations.

3. **Continuity** measures the number of disjoint track segments displayed relative to the number of target vessels. Note that in this experiment, each vessel can produce no more than one sonar track at a time.
4. **Correctness** measures the number of correct associations made relative to the to the total number of associations made.

The relative levels of development of the local operating picture will be compared with and without sonar track data shared by an allied vessel to determine the value of coalition data sharing at this level. The variance in this measure of improvement will be used to determine the number of subjects required for the main experiment.

Qualitative Measures

The number of times that each of the rationales was cited by an operator as a factor in his decision to associate two or more track segments into a master track will be analyzed to determine its relative value to the decision making process. The prepared list of association rationales offered to the operator will be revised based on the number of times each rationale was cited in the pilot experiment. Those rationales that were heavily cited may be broken down into subcategories. Rationales may be added or removed from the list used in the main experiment based on indications under the "other" category and feedback from the closing interviews in the pilot experiment.

A record of the execution of each experimental scenario will be made which will be suitable for reproducing the displays seen and the actions taken by the operator. Comments made by the subjects during the closing interview also will be recorded.

Medical Screening and Physician Coverage

No medical screening or physician coverage is required because this is a minimal risk study.

Risks

This experiment poses only minimal risk to the participants. No psychological measures will be taken and no emotionally distressing stimuli will be used. Participants are required to remain attentive. There is a risk of eyestrain and fatigue associated with viewing a computer monitor and operating a computer keyboard and mouse, but no greater than those associated with everyday computer use. Subjects will be free to leave at any time. *Data files and statements of performance will at no time be associated with the subject's identification to maintain anonymity.*

Approximate Time Involvement

Subjects will be asked to participate in a training session lasting about one hour, two simulations each lasting about two hours, and an interview lasting about half an hour. All of these activities can be scheduled into a single day including two 15 minute breaks and a half hour minute lunch break. The total time involvement will not exceed seven hours.

Remuneration

Participants will be reimbursed for their participation according to the DRDC Toronto stress allowance: $2.50 (Level I stress) x 7 hours + $10.14 (daily rate) = $27.64.

Benefits

This experiment will provide an opportunity to evaluate the feasibility and effectiveness of the described experimental technique in the pursuit of the indicated experimental objectives.

Comparison of the relative levels of operational picture development between the ownship alone, and ownship and cooperative allied ship scenarios will provide insight into the value of coalition sonar track data sharing. This experiment is the first of a planned series of experiments to investigate the value of sonar data sharing among coalition partners. In later experiments, these results will be used as a baseline for the evaluation of other data integration techniques at this and other levels of data development.

The cues and rationales employed by sonar operator in the process of passive sonar track association and disassociation can provide some direction in the development of algorithms for automated passive sonar track association. The availability of an automated passive sonar track association system could significantly reduce operator loading and decrease operator response time, especially in target-rich environments.

This experiment offers the participant an opportunity to share his or her expertise and participate in the development of future sonar analysis. The subjects will also be reimbursed for their participation.

Commercialization

The research findings resulting from this work could be used for commercialization purposes.

References

Mellema, G.R., "A methodology for the investigation and development of automated passive sonar track association," Defence Research and Development Canada – Atlantic, Canada, Technical Memorandum DRDC Atlantic TM 2002-195, Dec 2002.

Pigeau, R. (1992). Command Group's Guide to stress compensation for human subjects. Unpublished DRDC Document, DRDC Toronto.

"DRDC Toronto guidelines for human subject participation in research projects," Defence Research and Development Canada – Toronto, Apr 2002.

APPENDIX A

RECRUITMENT POSTER

RESEARCH PARTICIPANTS REQUIRED

Coalition passive sonar track sharing and association

PARTICIPANTS

Males and females between 18 and 65 years of age with normal or corrected to normal vision.

OBJECTIVES

This experiment will study the value of low-level coalition data sharing in the development of local operational picture.

PROCEDURE

Simulated sonar tracks similar to those presented by a passive towed array sonar system will be presented with or without corresponding tracks from an allied vessel at a geographically remote location. The participant's task is to use the available tracks as well as a navigational chart display and an initial situation report to develop a local operating picture. The session will last approximately 7 hours and includes some basic training.

WHEN

During normal working hours in September and October 2003.

WHERE

DRDC Atlantic, Number 9 Grove St., Dartmouth, Nova Scotia

COMPENSATION

Participants will be compensated according to DRDC guidelines.

For more information, all interested volunteers should contact:

Garfield Mellema at (902) 426-3100 x 252 / garfield.mellema@drdc-rddc.gc.ca
Tania Wentzell at (902) 426-3100 x283 / tania.wentzell@drdc-rddc.gc.ca

APPENDIX B

VOLUNTARY CONSENT FORM FOR HUMAN SUBJECT PARTICIPATION

Protocol Number: L-416

Research Project Title: Coalition passive sonar track sharing and association
Principal Investigator: Garfield R. Mellema
Co-investigator(s): Tania E. Wentzell

I, _____ (name) of _____ (address and phone number) hereby volunteer to participate as a subject in the study, "Coalition passive sonar track sharing and association" (Protocol # L-416). I have read the information package on the research protocol, and have had the opportunity to ask questions of the Investigators. All of my questions concerning this study have been fully answered to my satisfaction. However, I may obtain additional information about the research project and have any questions about this study answered by contacting the principle investigator Dr. Garfield R. Mellema at (902) 426-3100 ext 252.

I have been told that I will be asked to participate in one session of approximately seven hours in duration.

I have been told that the principal risks of the research protocol are: possible minor eyestrain and fatigue.

Also, I acknowledge that my participation in this study, or indeed any research, may involve risks that are currently unforeseen by DRDC Atlantic.

For Canadian Forces (CF) members only: I understand that I am considered to be on duty for disciplinary, administrative and Pension Act purposes during my participation in this experiment and I understand that in the unlikely event that my participation in this study results in a medical condition rendering me unfit for service, I may be released from the CF and my military benefits apply. This duty status has no effect on my right to withdraw from the experiment at any time I wish and I understand that no action will be taken against me for exercising this right.

I have been advised that the experimental data concerning me will be treated as confidential ('Protected B' IAW CF Security Requirements), and not revealed to anyone other than the DRDC Atlantic Investigator(s) or external investigators from the sponsoring agency without my consent except as data unidentified as to source. Moreover, should it be required, I agree to allow the experimental data to be reviewed by an internal or external audit committee with the understanding that any summary information resulting from such a review will not identify me personally.

I understand that I am free to refuse to participate and may withdraw my consent without prejudice or hard feelings at any time. Should I withdraw my consent, my participation as a subject will cease immediately, unless the Investigator(s) determine that such action would be dangerous or impossible (in which case my participation will cease as soon as it is safe to do

so). I also understand that the Investigator(s) or their designate responsible for the research project may terminate my participation at any time, regardless of my wishes.

I have been informed that the research findings resulting from my participation in this research project could be used for commercialization purposes.

I understand that for my participation in this research project, I am entitled to remuneration in the form of a stress allowance in the amount of $27.64 for each completed session for a total amount of $27.64 if I complete the entire research project.

I have informed the Principal Investigator that I am currently a subject in the following other DRDC Atlantic research project(s): _____ _____
(cite Protocol Number(s) and associated Principal Investigator(s)), and that i am participating as a subject in the following research project(s) at institutions other than DRDC Atlantic:
_____ (cite name(s) of institution(s))

I understand that by signing this consent form I have not waived any legal rights I may have as a result of any harm to me occasioned by my participation in this research project beyond all risks I have assumed.

Volunteer's Name _____ Signature: _____
_____

Date: _____

Name of Witness to Signature: _____

Signature: _____ Date: _____

Section Head/Commanding Officer's Signature (see Notes below)_____
CO's Unit: _____

Principal Investigator: Dr. Garfield R. Mellema, DRDC Atlantic
Signature: _____

Date: _____

FOR SUBJECT ENQUIRY IF REQUIRED:

Should I have any questions or concern regarding this project before, during, or after participation, I understand that I am encouraged to contact Defence R&D Canada (DRDC). This contact can be made by surface mail at this address or in person, by phone or e-mail, to any of the DRDC numbers and addresses listed below:

Principle Investigator (DRDC Atlantic):

Dr. Garfield R. Mellema, (902) 426-3100, garfield.mellema@drdc-rddc.gc.ca
Mail Address:

Dr. Garfield R. Mellema, Defence R&D Canada – Atlantic, PO Box 1012, 9 Grove St., Dartmouth, Nova Scotia, Canada B2Y 3Z7

Chair, DRDC Toronto Human Research Ethics Committee (HREC):

Dr. Jack Landolt, (416) 635-2120, jack.landolt@drdc-rddc.gc.ca
Mail Address:
Dr. Jack Landolt, Defence R&D Canada – Toronto, PO Box 2000, 1133 Sheppard Avenue West, Toronto, Ontario M3M 3B9

I understand that I will be given a copy of this consent form so that I may contact any of the above-mentioned individuals at some time in the future should that be required.

Notes:
For Military personnel on permanent strength of CFEME: Approval in principle by Commanding Officer is given in Memorandum 3700-1(CO CFEME), 18 Aug 94; however, members must still obtain their Section Head's signature designating approval to participate in this particular research project.
For other military personnel: All other military personnel must obtain their Commanding Officer's signature designating approval to participate in this research project.
For civilian personnel at DRDC Toronto: Signature of Section Head is required designating that the volunteer subject is considered to be at work and that approval has been given to participate in this research project.

List of acronyms

C2	Command and Control
DSTO	(The Australian) Defence Science and Technology Organization
HLA	High Level Architecture
HREC	Human Research Ethics Committee (at DRDC Toronto)
IM	Information Management
MAR	Maritime Systems Group (of TTCP)
RTI	Run-Time Interface
TMA	Target Motion Analysis
TP-1	Technical Panel 1 (of TTCP MAR)
TTCP	The Technical Cooperation Panel
UDF	Underwater Warfare Data Fusion (Group)
VBE	Virtual Battle Experiment
VCS	Virtual Combat Systems (Group)
VMSEM	Virtual Maritime System Execution Manager
VMSA	Virtual Maritime Systems Architecture
VMSSD	Virtual Maritime System Simulation Display

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This document outlines the experimental plan for the first Canadian Virtual Battle Experiment, VBE CA-1. It is intended to provide some context for the experiment and act as a blueprint and guide for its implementation and execution.
VBEs are being used by the Maritime Systems Group Technical Panel 1 of The Technical Cooperation Panel (TTCP MAR TP-1) to investigate the influence of Network Enabled Capability in a modular synthetic maritime environment. VBE CA-1 is the first of a series of experiments investigating the effect of sharing low-level passive sonar data. It was designed to use multiple subjects in multiple sessions of a human-in-the-loop experiment to produce statistically relevant results.

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